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Professional Group on Antennas and Propagation

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PROFESSIONAL GROUP ON ANTENNAS AND PROPAGATION

A QUARTERLY PUBLICATION DEVOTED TO EXPERIMENTAL AND THEORETICAL PAPERS ON ANTENNAS AND WIRELESS PROPAGATION OF ELECTROMAGNETIC WAVES

The Professional Group on Antennas and Propagation is an organization, within the framework of the IRE, of members with principal professional interest in Antennas and Propagation. All Members of the IRE are eligible for membership in the Group and will receive all Group publications upon payment of prescribed assessments.

Annual Assessment: $4.00

MANUSCRIPTS should be submitted to John B. Smyth, Editor, U. S. Navy Electronics Laboratory, San Diego, California. Manuscripts should be original typewritten copy, double spaced, plus one carbon copy. References should appear as footnotes and include author's name, title, journal, volume, initial and final page numbers, and date. Each paper must have an abstract of not more than 200 words. News items concerning PGAP members and group activities should be sent to the News Editor, Mr. H. A. Finke, Polytechnic Research and Development Company, 55 Johnson Street, Brooklyn, New York.

ILLUSTRATIONS should be submitted as follows: All line drawings (graphs, charts, block diagrams, cutaways, etc.) should be inked uniformly and ready for reproduction. If commercially printed grids are used in graph drawings, author should be sure printer's ink is of a color that will reproduce. All half-tone illustrations (photographs, wash, airbrush, or pencil renderings, etc.) should be clean and ready to reproduce. Photographs should be glossy prints. Call-outs or labels should be marked on a registered tissue overlay, not on the illustration itself. No illustration should be larger than 8 x 10 inches.

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news and views

PGAG Transactions

A MEETING of the PGAP Administrative Committee was held in San Francisco during the West Coast Convention. The most important subject of this meeting—and of the past few meetings—was the new TRANSACTIONS. It is hoped that by this time the entire membership has seen the first regular quarterly issue; this milestone in our history should be the occasion for justifiable pride.

Certain things are beginning to take shape. The Papers Committee is receiving an ample number of papers of top quality to indicate that the membership has already accepted this new publication as the official organ of their technical efforts. This rapid acceptance is a tribute to the aggressiveness and technical leadership of the people who are launching this journal. A financial problem exists, and this was not unexpected. In the long run, it is probably desirable that the TRANSACTIONS be financially self-sustaining. Presently, our source of funds is derived from membership dues, a minor income from institutional listings, and the remainder from IRE. Numerous devices exist for supplementing our present income sources. Sale of advertising space in the TRANSACTIONS, subscription rates to other than PGAP membership, etc., have been considered, but all involve careful liaison and approval from the parent Institute. The PROCEEDINGS will always be the official over-all organ of the Institute of Radio Engineers and, in that capacity, may be the logical recipient of most of the available advertising material.

We are in an interesting stage of transition wherein many problems must be worked out. Right now, with twenty-one Professional Groups in existence, it is not inconceivable that there could be twenty-one different TRANSACTIONS. On the surface, this would appear to represent a nice state of organized chaos. Actually, the signs point more in the direction of ultimate consolidation into, perhaps, no more than a half-dozen different TRANSACTIONS, with each publication embracing a somewhat broader scope than at present, and with the PROCEEDINGS at the top of the pyramid, coordinating and embracing in a more general fashion the scope of all.

IRE Committee on Antennas and Waveguides

The IRE Committee on Antennas and Waveguides has devoted a great deal of effort toward the development of standard definitions of waveguide terms. A rather complete set of definitions, long in preparation, will shortly be issued in the PROCEEDINGS. It is surprising to realize the problems which can arise in attempting to define even some relatively simple terms. Much fundamental thinking by a large number of people had to be done to reconcile various differences of opinion. After acceptance by the Antennas and Waveguides Committee, each definition required the further discussion and approval of the Standards Committee.

A most interesting example was represented by the Committee's attempts to define the quantity Q which, on the surface, would appear to represent a most elementary problem. To indicate the nature of the effort involved in what is, admittedly, a more difficult case, the following comment by A. G. Fox, a committee member, is quoted:

"Report on Q Definition"

"I have given consideration to the criticism of the Antennas Committee's definition for Q, which, in the case of a coil, appears to give the wrong answer. If we concern ourselves only with the problem of how to define Q on an energy basis, so that it will give the right answer for a coil or for a coil-condenser resonant circuit, we can accomplish this by using in the definition the maximum value of stored energy occurring during one cycle. However, the definition based on the use of maximum stored energy will definitely give the wrong answer for a transmission line or propagation medium, since the maximum value of energy stored within a short section of transmission line will be a fraction of its length. For an extremely short section of line the maximum value of stored energy will be twice the average value. A half wave length section will have a maximum value which is equal to the average value. Since we are disposed to regard the Q of a medium as a figure of merit which is intrinsic for the medium, we do not want a definition which gives variable results depending upon how large a

portion of the medium we examine. Moreover, past usage has been consistent with the average energy definition.

"It now appears to me that the definition of Q for a coil as the ratio of the reactance to the resistance is the result of accident. If we examine the mathematical expression for the impedance of a parallel resonant circuit, we find in the denominator a term which contains $\omega L/R$ and a frequency variable. The $\omega L/R$ was chosen as the Q factor since it determined the rate at which the impedance varied with change in frequency. This same $\omega L/R$ appears in the exponential which determines the rate at which energy stored in the resonant circuit will die away. Since the Q of most resonant circuits is determined primarily by the coil, it was natural to take this same ratio as the Q of the coil alone. This may have been convenient, but it was indeed an illogical choice. As a matter of fact, if we examine the rate at which energy dies away from a coil which has been excited with a current and then shorted upon itself, we find that the decrement is twice as great as for the coil and condenser combination. Therefore, logically, the Q of a coil alone should be one half as great as the Q of the parallel resonant circuit, and should be equal to $\omega L/2R$. This is the result that we get using the average energy definition. As pointed out during our earlier consideration of this definition, Q should really be a measure of the ability of an energy storage element to hold on to the energy that has been put into it.

"Notwithstanding these arguments, it is obvious that we are not going to be able to change the definition for Q of a coil which has had so much precedent. We may note that the seeming conflict occurs not because of a mistake in our definition or in my earlier derivation for the Q of a transmission medium, but arises fundamentally from an insonsistency in the first usage of the term. It is interesting that this dilemma is not brought out in most text books which define Q. A number of examples have been found in which Q was defined on an energy basis, but in nearly all cases, there is complete vagueness on what is meant by "energy stored," that is, whether it is "average energy stored" or "maximum energy stored."

"It seems to me that in order to avoid further difficulty, we should simply recognize that our definitions for Q of a medium and Q of a waveguide really apply only to the cases which we have given, and must not be applied to a coil or condenser. They can be applied to any resonant circuit which is operating at its resonant frequency. I do not believe that our definitions require a change."

If any of our readers have any comments of their own on the problem of defining Q, we should be most happy to hear from them.

Another kotty definition was "direction of propagation" in waveguide. We should like to think of the direction of propagation in a waveguide as being along the axial direction. However, the direction of net energy transfer in dissipative systems is not axial to the waveguide. This question has some lively possibilities, although admittedly, the answer here must be opinionated.

Another interesting result of the Committee's work is that when the Standards are issued, in official terms for the first time, waveguides and transmission lines will be regarded as basically the same thing.

This Committee has been ably headed by Delmer C. Ports who has done a fine job of guiding the thinking toward the establishment of the definitions that will now appear in the PROCEEDINGS as standard for the industry.

New PGAP Officers

The new officers for the term of June 1, 1953 to May 3' 1954, who are the members of the administrative committee of the Professional Group on Antennas and Propagation as well, have been elected as follows:

		Term Expires
Chairman:	P. S. Carter	'54
Vice-Chairman:	D. C. Ports	'55
Secretary-Treasurer:	P. H. Smith	'54
Senior Past Chairman; Chairman-Membership Committee	George Sinclair	'56
Junior Past Chairman: Coordinator with other Organizations:	A. H. Waynick	'54
Editor:	J. B. Smyth	'55
Chairman-Papers Review Committee:	H. G. Booker	'55
News Editor:	H. A. Finke	'56
Chairman-Chapters Committee:	J. S. Brown	'55
Chairman-Papers Procurement Committee:	L. J. Chu	'54
Advertising	R. B. Jacques	'54
Honorary Member:	L. C. Van Atta	
Past Editor:	H. W. Wells	'56
Chairman-Meetings Committee:	J. T. Bolljahn	'56

LOCAL CHAPTERS

Professional Group activity at the chapter level is one of the ultimate aims and a very important phase of the whole PG movement. With the national group as a supporting organization, local activity provides the opportunity for specialized papers and get-togethers of engineers with mutual interests in a specific field.

The PGAP has, at present, two active chapters, Los Angeles and Chicago. There should be more. The fol-

lowing list shows the IRE sections with the largest PGAP memberships:

Atlanta	36
Baltimore	41
Boston	75
Chicago	73
Dallas-Ft. Worth	28
Los Angeles	109
New York	102
Long Island (Sub-section)	83
Monmouth (Sub-section)	36
New Jersey (Sub-section)	65
Philadelphia	55
San Diego	26
San Francisco	83
Syracuse	61
Washington, D. C.	165

All of these Sections should have local chapters. The national PGAP organization stands ready to help any Section interested in establishing a chapter.

Why not get more out of your PGAP by stirring up some local activity? Talk to your Section chairman (or Professional Groups committee chairman, if you have one). Write to J. S. Brown, Chairman, Local Chapter Committee at Andrew Corporation, 363 E. 75th Street, Chicago 19, Ill., for details on how to get started.

Meetings

Joint URSI-IRE Meeting, Ottawa, Canada

The PGAP is sponsoring a Fall Technical Meeting jointly with the USA National Committee of the International Scientific Radio Union (URSI) and the Canadian National Committee, URSI. This meeting will be held on October 5, 6, 7 and 8, 1953 at the National Research Council, and the Defense Research Board, Ottawa, Canada.

A meeting of the USA National Committee and meetings of participating Commissions will be held on Monday, October 5. The technical sessions will be held on Tuesday, Wednesday and Thursday, October 6, 7, and 8.

The participating Commissions and their chairmen are:

Commission 1 Radio Measurement Methods and Standards
Chairman: Dr. Rufus G. Fellers, USA
Dr. J. Y. Henderson, Canada

Commission 3 Ionospheric Radio Propagation
Chairman: Dr. L. V. Berkner, USA
Mr. J. C. W. Scott, Canada

Commission 4 Terrestrial Radio Noise
Chairman: Mr. Frederick H. Dickson, USA
(Associated with Commission 3 in Canada)

Commission 5 Radio Astronomy
Chairman: Dr. John P. Hagen, USA
Mr. A. E. Covington, Canada

Commission 7 Electronics
Chairman: Dr. J. R. Whinnery

Conference on Radio Meteorology, University of Texas

The Conference on Radio Meteorology will be held on November 9, 10, 11, and 12, 1953 at the University of Texas, Austin, Texas. Commission 2 on Tropospheric Radio Propagation is a sponsor of the Conference. Technical sessions on the following groupings have been planned:

Tropospheric Propagation

1. Tropospheric Propagation Well Beyond the Horizon—A Review; T. C. Carroll. (Invited.)
2. Propagation Characteristics of 0.86 Centimeter Radio Waves; C. W. Tolbert and A. W. Straiton.
3. Field Strength Determination by Ray Tracing Techniques for Horizontally Stratified Layers; B. M. Fannin.
4. Calculated Centimeter-Millimeter Water Vapor Absorption at Ground Level; T. R. Rogers.
5. Characteristic Effects of Atmospheric Stratification on Air-to-Air Propagation; P. B. Taylor.
6. The Anomalous Propagation of the Longer VHF Waves; F. H. Northover.
7. Prolonged Space-Wave Fade Outs of the 1046 MC Cheyenne Mountain Experiment; B. R. Bean.
8. The VHF-UHF Propagation Studios of the National Bureau of Standards—A Review; J. W. Herbstreit. (Invited.)
9. Factors Influencing Propagation of VHF Waves in the Diffraction Zone; W. G. Albright and R. N. Ghose.

Refractive Index Meteorology and Climatology

1. Summary and Preliminary Analysis of Tropospheric Refractive Index Measurements; C. M. Crain and J. R. Gerhardt.
2. The Monthly Refractivity Gradient for the United States and its Application to Predicting the Geographical and Annual Trends of 100 MC Field Strengths; B. R. Bean and F. M. Meaney.
3. Verification of Surface-Duct Propagation Predictions; L. J. Anderson and E. E. Gossard.
4. Prediction of Diurnal Field Strength Patterns by Synoptic Methods; F. R. Bellaire and W. A. Arvola.
5. A Radio Climatology Survey of the U. S.; L. W. Cowan

Atmospheric Scattering and Turbulence

1. Radio Scattering from a Turbulent Elevated Layer; W. E. Gordon.

2. A Meteorological Study of Angles at 1.25 Cms.; V. G. Plank.
3. Reflection of Pulses from Atmospheric Dielectric Variations; D. M. Swingle.
4. Diffusion of a Smoke Puff as a Turbulence Measure in the Atmosphere; E. Inoue.
5. Structure of Two and Three-dimensionally Isotropic Turbulence in the Atmosphere; Y. Ogura and K. Yakoda.

Thunderstorm and Tornado Atmospherics

1. Correlation of Thunderstorm Atmospheric Measurements; J. Weil and M. M. Newman.
2. The Lightning Discharge Propagation Mechanism effect on Atmospherics Waveforms including "Whistlers"; M. M. Newman.
3. Recording and Classification of Thunderstorm Atmospherics by Counter Techniques; M. M. Newman, J. R. Stahmann, and J. R. Anderson.
4. Lightning Identification on the PPI; D. M. Swingle.
5. Atmospheric Wave Forms and the Location of Thunderstorms; E. T. Pierce and T. W. Wormell.
6. The Physical Processes in the Development of Tornadoes and Consequences which Influence Their Dissipation; F. O. Rossman.
7. The Destruction of Tornadoes with Missiles Guided by Weather Radar; R. H. Mayer.

Interpretive Techniques in Radar Meteorology

1. Interpretive Techniques in Radar Meteorology—A Review; P. M. Austin. (Invited.)
2. Quantitative 1.25 Cm. Observation of Rain and Fog; R. J. Donaldson, D. Atlas, W. H. Paulsen, R. C. Cunningham and A. C. Chmela.
3. Moisture Content, Distribution and Radar Reflectivity in Thunderstorms; R. K. Moore, H. G. Oltman, A. T. Marrs and D. M. Gragg.

Operational Uses of Weather Radar

1. The Use of Radar Storm Observations for Weather Forecasting—A Review; M. G. H. Ligda. (Invited.)
2. The Radar Storm Detection Program of the Weather Bureau; V. D. Rockney.
3. The Frequency of Radar Storm Echoes As a Function of Position; W. J. Richards.
4. The Variability of the Motion of Radar Precipitation Lines; D. M. Swingle and W. J. Richards.
5. Mesometeorological Analysis of Color Front Passage Using Radar Weather Data; D. M. Swingle and L. Rosenberg.
6. Operational Uses of Radar Storm Observations; M. G. H. Ligda.
7. Radar Forecasting on Lake Ontario; A. D. Hood and L. H. Doherty.
8. Radar Observations of the Sea-Breeze Front; D. Atlas, W. H. Paulsen, R. J. Donaldson, A. C. Chmela and V. G. Plank.
9. Radar in Single Station Analysis; G. E. Stout.
10. A review of Results of Operational Tests of Radar Cloud Indicating Equipment; D. M. Swingle.
11. Radar Echoes in Tornado Situation; J. C. Freeman, Jr.
12. Summary and Results of the First Texas Tornado Warning Conference; A. M. Kahan.

Radar Rainfall Determination

1. Measurement and Detection of Rainfall by Radar at Attenuating Wave Lengths; W. Hitschfield.
2. Reliability of Radar Areal Rainfall Measurements; F. A. Huff and J. C. Neill.
3. Variance of Areal-Mean Thunderstorm Rainfall Estimates; J. C. Neill.

Cloud and Precipitation Physics

1. Cloud Physics—A Review; S. E. Reynolds. (Invited.)
2. Application of Radar to Cloud Physics Research in Hawaii; D. S. Johnson.
3. Radar Observations of Snow; R. Wexler and P. M. Austin.
4. Lowering of the Bright Band during Heavy Rain; R. Wexler and J. Honig.
5. The Deformation of Large Raindrops; J. E. McDonald.
6. Radar Evidence of a Generating Level for Snow; K. L. S. Gunn.
7. Development During Fall of Raindrop Size Distributions; J. S. Marshall.

Personals

Jansky and Bailey, Washington consultant engineers who have been in business since 1930, have recently been changed to a corporation. No changes in personnel are contemplated, but considerable benefit and improvement in efficiency is expected from the new corporate structure.

PGAP has accepted with great regret Dr. L. C. Van Atta's resignation from the Administrative Committee. His valuable experience will still be available to the Committee, as he has agreed to accept honorary membership.

In recent organization changes at the Andrew Corporation, J. S. Brown was promoted to Director of Engineering, heading all phases of the company's engineering and development program. L. R. Krahe was made Head of the Advance Development Group at the Antenna Laboratory Located at Orland Park, Ill. M. W. Scheldorf has been appointed Engineering Consultant.

contributions

The Effect of Radar Wavelength on Meteor Echo Rate*

VON R. ESHLEMAN†, ASSOCIATE, IRE

Summary—**A new theory is given for the way in which the number of echoes received from sporadic meteor ionization trails varies with radar wavelength and other system parameters. Previously-published explanations of the echo rate dependence on wavelength are critically examined. The present explanation of echo rate variations is based upon a more complete analysis of the radio reflection process than is afforded by the Lovell-Clegg theory. The effects of high electron density, the linear rate of trail formation, and the initial column radius are discussed. A number of apparent conflicts in earlier investigations are reconciled by the new theory.**

Introduction

At the present time, uncertainty exists as to the manner in which the rate of occurrence of radio echoes from the ionization trails of sporadic meteors varies with wavelength and other system parameters. A. C. B. Lovell and co-workers at the University of Manchester have stated that their theory of reflection from meteor trails explains the echo rate observed on short wavelengths (from about 1.4 to 6 meters), but not on the longer wavelengths (above about 8 meters)[1,2] On the other hand, D. W. R. McKinley, of the Canadian National Research Council, has published results which indicate that this theory predicts correctly the number of echoes obtained on the longer wavelengths, but not on short wavelenghts.[3] The purpose of this paper is to suggest that: (1) the deductions made by Lovell concerning the applicability of his theory to the explanation of echo rate variations may not be justified, and (2) McKinley's experimental results are consistent with a more complete picture of the radio reflection process than is given by the original theory taken alone. The new theory of echo rates includes the effects of high electron density, the linear rate of trail formation, and the initial column radius upon the meteor echo power and hence upon the number of received echoes.

Outline of the Problem

The Manchester group was the first to point out the apparent echo rate dependence on wavelength, and the lack of a theoretical explanation thereof. An attempt will be made to outline briefly their published account of this problem. In measurements on wavelengths from 1.4 to 6 meters, Lovell and his co-workers have used radars which detect about 10 echoes per hour from non-shower meteors. This corresponds roughly to the number of sporadic meteors which could be observed visually on a clear, moonless night. However, Lovell has stated that with equipment of "equivalent" sensitivity operating on longer wavelengths, these visual-type echoes are submerged in an extremely high background rate of several hundred echoes per hour.[1] There can now be little doubt that these more numerous echoes are also from columns of ionization created by meteors, but visual correlations are not feasible because of the low luminosity of the smaller trails.

The Lovell-Clegg reflection theory[2] relates the number of electrons per unit of length along a meteor trail and the amplitude of the radio echo received by scattering from these electrons. The wavelength dependence of echo amplitudes from individual trails was measured by these authors for wavelengths between 1.4 and 8.3 meters, and found to be in agreement with their theory. (It will be shown later that another theory of radio re-

* Prepared under Contract N6-ONR-251 Consolidated Task No. 7(NR-078-360) for Office of Naval Research, the Signal Corps, and the U. S. Air Force.

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[1] A. C. B. Lovell, "Meteoric ionization and ionospheric abnormalities," *Phys. Soc. Rep. Prog. Phys.*, vol. 11, pp. 415–444; 1948.

[2] A. C. B. Lovell and J. A. Clegg, "Characteristics of radio echoes from meteor trails: I. The intensity of the radio reflections and electron density in the trails," *Proc. Phys. Soc.* (London), vol. 60, pp. 491–498; 1948.

[3] D. W. R. McKinley, "Variation of meteor echo rates with radar system parameters," *Canadian Jour. Phys.*, vol. 29, pp. 403–426; 1951.

flection from meteor trails predicts the same variation of echo amplitudes with wavelength.) Lovell and Clegg also stated that the measured absolute echo signal strengths for visible meteor trails, when related to the line density of electrons by their formula, were in agreement with Herlofson's theory[4] concerning the ionizing efficiency of meteoric particles. (Later measurements at Stanford University[5] and at the University of Manchester,[6] however, indicate that meteor trail line densities are about two powers of ten greater than given by this theory.

The Manchester group has computed the distributions of electron line densities for the meteor trails of the 1946 Giacobinid shower, and later for the 1946 Geminid and 1947 Quadrantid showers.[1,7] This was accomplished by relating echo signal strength, measured at a wavelength of 4 meters, to the electron line density by use of the Lovell-Clegg formula. In each case, it was found that the number of echoes was approximately inversely proportional to the electron line density. On the basis of Herlofson's theory, the line density of electrons in a meteor trail is directly proportional to the meteoric mass for particles of the same velocity. Thus, Lovell has concluded that the number of meteoric particles in these showers was inversely proportional to their mass, which he claims is in agreement with the visual observations of Watson[8] on sporadic meteors.

Presumably, the above-mentioned experimental results are the bases of Lovell's statement to the effect that his formula predicts correctly the variation of sporadic echo rate with wavelength from 1.4 to 6 meters, but fails completely to account for the sudden increase in the number of echoes received on wavelengths above 8 meters.[1] Two independent objections to such a conclusion may be raised at this point. (1) The Poynting-Robertson dispersion effect is expected to make the particle mass distribution in meteor showers different from that for sporadic meteors. In particular, theory and experiment indicate that there is a larger percentage of large meteors during showers than during a non-shower period. (2) Watson's observation that the same meteoric mass is incident upon the earth's upper atmosphere from sporadic meteors of each visual magnitude range infers that the number of meteors is inversely proportional to the *square* of their mass. That is, if we plot a curve of the number of incident meteoric particles in equal mass increments *vs.* mass, we would expect, according to Watson's observations, an inverse square law dependence. Lovell measured an inverse first law dependence,[7] and claimed agreement with Watson's results. The confusion may have resulted from the common use of integrated echo rates. If the number of meteors is inversely proportional to the square of their mass, the integrated rate is inversely proportional to mass; i.e., the number of particles of mass m or larger is inversely proportional to m.

The method employed by Lovell in determining the echo rate dependence on wavelength was based on two different types of experimental results; *viz.*, the echo amplitude variation with wavelength and the echo rate dependence on amplitude. This method should be valid, though somewhat circuitous, if properly applied and interpreted. On the other hand, McKinley has made direct measurements of sporadic meteor echo rate as a function of wavelength, and other radar system parameters.[3] In measurements of the wavelength dependence of the echo rate, McKinley found that the ratio of the numbers of echoes received on his 9.22 and 5.35 meter radars was about the same as predicted by the Lovell-Clegg formula. However, the ratio of the 9.22 meter radar rate to his 2.83 meter radar rate was more than twice the expected value. In comparng the experimental results with the Lovell-Clegg theory, McKinley assumed that the integrated number of sporadic meteors is inversely proportional to their mass, and that the ionizing efficiency of the particles is independent of their mass. McKinley's results confirm Lovell's observation that the echo rate increases rapidly as the frequency is lowered. However, in direct contrast with Lovell's statement, these results also imply that the Lovell-Clegg formula may apply to the numerous, low-line-density trails observed on the longer wavelengths, but not to the higher density, visual-type trails.

Theoretical Explanation

It will be shown that wavelength changes affect the rate of detection of meteor echoes in two ways which are not predicted by the Lovell-Clegg formula. The most important effect is believed to result from the non-applicability of this formula for the high-density, visual-type trails. In addition, the linear rate of formation of the trails and their initial radius will be shown to have an important effect upon the amplitude of the echoes, and hence upon their rate of detection, for the shorter wavelengths.

In MKS units the corrected[9] Lovell-Clegg formula becomes

$$\frac{P_R}{P_T} = \left[\frac{G_R G_T}{32\pi^4}\left(\frac{\lambda}{R}\right)^3\right]\left(\frac{\mu_0 e^2}{4m}\right)^2 q^2 \tag{1}$$

where

P_R—maximum peak echo power at input of a receiver matched to the receiving antenna

[4] N. Herlofson, "The theory of meteor ionization," *Phys. Soc. Rep. Prog. Phys.*, vol. 11, pp. 444–454; 1948.

[5] V. R. Eshleman, "The Mechanism of Radio Reflections from Meteoric Ionization," Technical Report no. 49, Electronics Research Laboratory, Stanford University, Stanford, Calif.; 1952.

[6] J. S. Greenhow and G. S. Hawkins, "Ionizing and luminous efficiencies of meteors," *Nature* (London), vol. 170, pp. 355–357; 1952.

[7] A. C. B. Lovell, C. J. Banwell, and J. A. Clegg, "Radio echo observations of the Giacobinid meteors 1946," *Mon. Not. R. Astr. Soc.*, vol. 107, pp. 164–175; 1947.

[8] F. G. Watson, "Between the Planets," The Blackiston Co., Philadelphia, Pa., pp. 114–117; 1941.

[9] The original Lovell-Clegg formula is in error, being only $\frac{1}{2}$ of the value given by (1).

P_T—peak transmitted power

G_R, G_T—receiving and transmitting antenna power gains over an isotropic radiator in the direction of the meteor trail, respectively

λ—wavelength

R—range from the common transmitter-receiver site to the meteor trail

μ_0—permeability of free space

e—electronic charge

m—electron rest mass

q—total number of electrons per meter of length along the meteor trail

In addition, if the trail expands from a line source according to the normal diffusion equation, the time dependence of the echo power amplitude is given by $\exp(-32\pi^2 Dt/\lambda^2)$. In this expression, $\exp = 2.718 \cdots$, D is the diffusion coefficient (about 3 meters^2 per second), and t is measured from the time of formation of the line source.

In the derivation of (1), it was assumed that the incident wave is not attenuated in passing through the column and that the electrons scatter freely and independently. It has been shown[5,10] that these assumptions are no longer valid when the line density of electrons, q, is greater than about 10^{14} electrons per meter. If only the fairly bright visual meteors (+1 magnitude and less) produce 10^{14} or more electrons per meter, as originally suggested by Herlofson and by Lovell and Clegg, this limitation would not be important because of the statistically small number of bright, visual meteors. However, more recent measurements indicate that the faintest visible meteor trails (+6 magnitude) contain about 10^{14} electrons per meter.[5,6] This is an additional reason for questioning the validity of Lovell's conclusion about the rate-wavelength dependence. That is, since the majority of meteors detected during his experiments were of visible size, it is now seen that the electron density in these trails exceeded the maximum which could be taken into account by the Lovell-Clegg theory.

Scattering from the high-density trails may be analyzed by assuming total reflection from the radius of critical electron density, as in the case of ionospheric layers. Electrons spreading by normal diffusion from a line source produce a column with a Gaussian radial distribution of electrons. The critical density radius of such a column reaches a maximum at 37 per cent of the total time between trail formation and the time of disappearance of a critical density due to diffusive expansion. For total reflection at this maximum critical radius, it can be shown that the maximum value of P_R is given by

$$\frac{P_R}{P_T} = \left[\frac{G_R G_T}{32\pi^4}\left(\frac{\lambda}{R}\right)^3\right]\left(\frac{\pi}{4\exp}\right)^{1/2}\left(\frac{\mu_0 e^2}{4m}\right)^{1/2} q^{1/2}. \qquad (2)$$

This expression has a value which is one-half of that of the corresponding formula derived by Greenhow,[11] which is believed to be in error. The time dependence of the echo power for the dense trails is given by $[at \ln(b/t)]^{1/2}$, where a and b are constants. Note that the experimental observations of Lovell and Clegg on the wavelength dependence of signal strength from individual trails does not differentiate between the applicability of (1) or (2) to the reflection process.

In deriving (1) and (2), and their time dependencies, it was assumed that the trail is formed from a line source. However, the velocity of the meteoric particle which produces the trail is finite (between 11 and 73 km/sec), so that the source is not formed instantaneously. Thus, the radius to which the trail has expanded is not the same for various positions along the length of the trail. In addition, it is believed that the ionization column is formed with an initial radius—at the meteoric particle—on the order of a molecular mean free path.

The effect of the non-zero initial trail size can be taken into account by replacing t in the expressions for the time dependence of the echoes by $t + r_0^2/4D$, where r_0 is the molecular mean free path for the meteor ionization region of the ionosphere.

In order to treat the problem of non-uniformity in length, the time factor is made a function of position along the trail axis and of the meteoric velocity. An exact analysis results in Fresnel integrals with complex limits which are not tractable. A simple approximation can be justified from the following arguments. A very long or infinite line of electrons produces the same scattered field as a line of the same line density only $(\lambda R)^{1/2}$ long if it is assumed in the latter case that all the electrons scatter coherently.[5] But along this length—centered at the specular reflection point—of the infinite line, the electrons scatter very nearly in phase. That is, all the remaining electrons cause small variations in the echo strength, but no increase in the average value. A good approximation to the echo power from a meteor trail can thus be obtained by considering only the $(\lambda R)^{1/2}$ length which is centered at the specular reflection point, and by assuming that there are no phase effects associated with position along this length.

Since the maximum signal strength for the trails of low line density occurs at minimum radius, the maximum echo power including the finite velocity and initial size effects should occur at the instant of complete formation of the trail length segment described above. Thus, the ratio of the received power including the size and velocity effects (P_R') to the received power given by (1) is

$$\frac{P_R'}{P_R} = \frac{1}{\lambda R}\left\{\int_0^{(\lambda R)^{1/2}} \exp\left[-\frac{16\pi^2 D}{\lambda^2}\left(\frac{z}{v} + \frac{r_0^2}{4D}\right)\right] dz\right\}^2$$

[10] N. Herlofson, "Plasma resonance in ionospheric irregularities," *Arkiv för Fysik*, vol. 3, pp. 247–297; 1951.

[11] J. S. Greenhow, "Characteristics of radio echoes from meteor trails: III. The behaviour of the electron trails after formation," *Proc. Phys. Soc.* (London), vol. 65, pp. 169–181; 1952.

$$= \frac{\lambda^3 v^2}{64\pi^4 D^2 R} \exp\left[-8\pi^2\left(\frac{r_0^2}{\lambda^2}+\frac{2DR^{1/2}}{\lambda^{3/2}v}\right)\right]$$
$$\cdot \sinh^2\left(\frac{8\pi^2 DR^{1/2}}{\lambda^{3/2}v}\right) \qquad (3)$$

where v is the meteoric velocity.

The echo strength of the high-density trails is only slightly affected by v and r_0 over the range of parameters which will be considered here. That is, since the echo power exhibits a broad maximum in time, and since this maximum occurs at a large trail size, the non-uniformity in length and the initial column radius alter the maximum echo power very little from the value given by (2). In fact, an approximate solution for representative values of v, r_0, D, and R indicates that for $\lambda=1.0$ meters and $q=10^{15}$ electrons/meter, the echo power is only about 1.5% less than if the trail had been formed from a line source. Thus, no correction will be made in equation (2) for finite values of v and r_0.

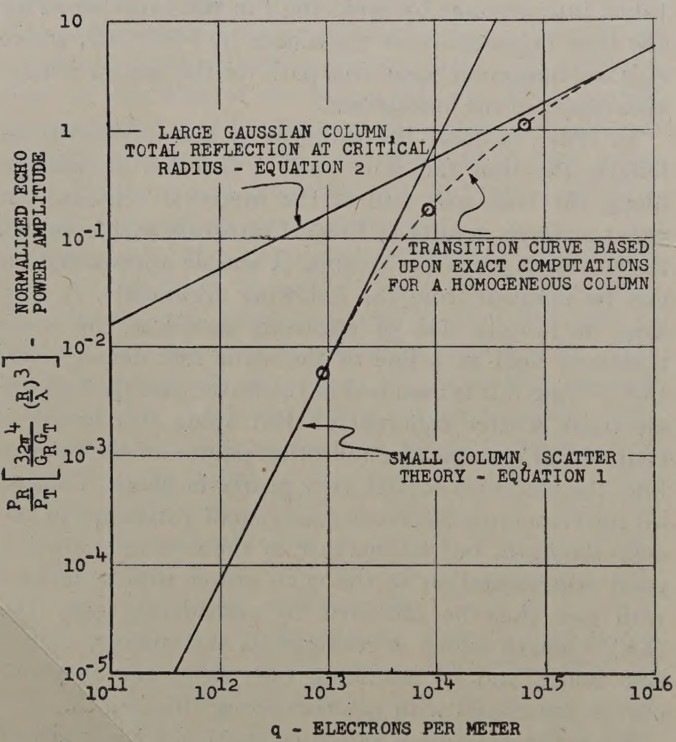

Fig. 1—Maximum meteor echo power amplitude as a function of electron line density in the trail. The trail is assumed to expand from a line source.

In Fig. 1, normalized expressions for P_R are plotted from (1) and (2) as a function of line density, q. (1) may be used for line densities below about 10^{14} electrons per meter, while (2) applies for greater line densities, assuming that the trail expands from a line source. Equation (1) does not apply for line densities above 10^{14} electrons per meter since the incident wave is attenuated inside the column and no longer excites all the electrons equally. Equation (2) is not valid for line densities below this amount since the radius at which the volume density is critical is too small for the evanescent wave to be appreciably attenuated.[5] Thus, total reflection does not occur at this radius.

The transition between the two curves in Fig. 1 must be found from exact solutions for assumed trail models. Because of the difficulty in obtaining an exact solution in this density range, numerical values have been computed only for a homogeneous model, where the electrons are uniformly distributed throughout a cross section of the cylindrical column.[5] Three computed points in the transition region are indicated by circles in Fig. 1. Thus, the dashed line joining the curves and passing through these points appears to be a reasonable representation of the relationship between the maximum echo power amplitude and the electron line density when the ionization column is formed from a line source.

The effect of v and r_0 on the wavelength dependence of maximum echo amplitudes is computed from (3) and pictured in Fig. 2 for the following average values: $v=40$ km/sec, $D=3$ m^2/sec, $r_0=0.10$ m, and $R=150$ km. For wavelengths above about 10 meters, (3) is essentially unity so that the resultant curve of Fig. 1 is repeated in Fig. 2 for these wavelengths. Other curves are then plotted for $\lambda=4$, 2 and 1 meters in the low density region and joined to the values given by (2) in a manner similar to that which was determined for the transition region in Fig. 1. The dashed line in Fig. 2 represents the Lovell-Clegg formula, equation (1). For wavelengths below about 1 meter, it is expected that the curves will have an inflection point, such as is shown in the dotted line of Fig. 2 for $\lambda=0.5$ meters. That is, the effect of v and r_0 upon echo strength is much more pronounced for the low density trails than for the high density trails, so that a rapid rise in echo strength is obtained for the shorter wavelengths at line densities near 10^{14} or 10^{15} electrons per meter.

The magnitude of the maximum echo power at the input terminals of a receiver, P_R, depends upon the transmitted power, the transmitter and receiver antenna gains in the direction of the meteor trail, the radio wavelength, the range to the trail, and the line density of electrons in the meteor column. With the exception of the electron line density, all of these factors are included with P_R in the quantity plotted as the ordinate in the figures. It will be convenient to use this normalized expression as a measure of the over-all system sensitivity to a particular meteor trail. That is, if the minimum input power detectable by a given radar receiver is normalized by these factors to obtain an ordinate for the curves in Fig. 2, the corresponding abscissa will be the minimum line density a trail may have and still be detected. Note in particular that the wavelength enters into both the ordinate value and the selection of a member of the family of curves in Fig. 2. That is, the wavelength is a factor in the system sensitivity and in the effect of v and r_0 on the maximum echo power.

Radars operating at different wavelengths, but hav-

ing antennas whose dimensions, measured in wavelengths, are the same, will illuminate the same volume of atmosphere. The manner in which the intensity of this illumination varies over the volume is also the same. For such radars, a direct comparison of observed echo rate with theory may be made. That is, keeping in mind the previous assumption as to the integrated meteor rate dependence on electron line density, the curves in Fig. 2 may be used to find the echo rate as a function of radar wavelength and over-all system sensitivity. Since the echo rate varies from hour to hour, the abscissa is calibrated in terms of echo numbers with an arbitrary reference of one echo per hour from trails of line density 10^{15} electrons per meter or greater. That is, the numbers scale should be used only to determine rate ratios for radars of different sensitivities, and operating on different wavelengths, and not to determine absolute numbers of echoes.

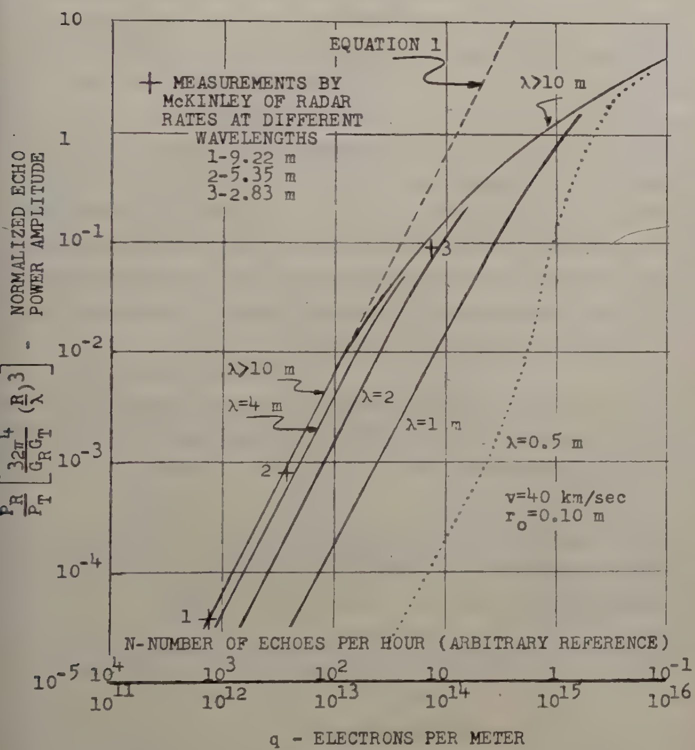

Fig. 2—Maximum meteor echo power amplitude as a function of line density and wavelength for average values of meteoric velocity and initial trail size. These curves also show a theoretical relationship between radar system sensitivity and relative numbers of echoes for the various wavelengths.

If the number of echoes received on radars with different antenna types are to be compared, allowances must be made for the differing volumes illuminated, and for differences in the probability of detecting meteor trails within these volumes. A meteor trail gives a strong reflection only when the incident ray from the common transmitter-receiver site meets the trail axis at right angles. For uniformly distributed meteor radiants, the probability that a trail at a given position relative to the transmitter-receiver site will be oriented to produce a reflection, is a function of this position.[12] Thus, if two radar systems illuminate different volumes of the upper atmosphere, the fraction of meteors detected in each volume will not, in general, be the same.

Now it shall be shown that the curves of Fig. 2 have the characteristics needed to explain the results of the rate-wavelength experiment made by McKinley. The antenna systems for this test were geometrically similar and scaled in size by the wavelength factor. The ordinates of the points indicated by crosses were computed for the system parameters of the 9, 5 and 2.8 meter radars used in this test. An average range of 150 km was used for these computations, where the corresponding average antenna gain is about 3. The value for P_R is taken as 6 db below the noise level, since McKinley indicates that his film records were read to this level. The abscissas of these points correspond to the relative numbers of echoes that were obtained. Only the count for 0400–0500 local time was used for the 5.35 meter radar rate, since McKinley indicates that the earlier counts included Perseid shower meteors. It is apparent that neither (1) nor (2) alone could explain the observed results. Note that the deviation of the 2.83 meter point in Fig. 2 from the Lovell-Clegg line is about half due to the true wavelength effect (i.e., the effect of λ on echo strength as indicated by equation (3)), and about half due to the wavelength dependence of over-all system sensitivity (i.e., the curvature in the $\lambda > 10$ meter line resulting from the nonapplicability of (1) in the high line density region). However, it is believed that the low rates observed by Lovell on wavelengths below about 6 meters were primarily due to low system sensitivities. That is, these radars were adjusted so that the radar rate corresponded roughly to the visual rate. Thus, the equipment could only detect echoes from trails whose line densities were above about 10^{14} electrons per meter. Reference to Fig. 2 shows that in this region, the primary cause of departure from (1) is the low over-all sensitivity and not the true wavelength effect given by (3). Therefore, an increase in transmitted power or receiver sensitivity in this case would result in an increase in radar rate greater than that predicted by the Lovell-Clegg formula.

Conclusions

It has been shown that the variation of the sporadic meteor echo rate with wavelength may be due not only to the change in frequency *per se*, but also may be caused by the difference in over-all system sensitivity to meteor ionization columns which accompanies frequency changes. That is, there is a true wavelength effect on echo power and hence echo rate associated with the velocity of the meteoric particle and the initial trail size. In addition, since (1) does not apply to the high

[12] V. R. Eshleman and L. A. Manning, "Radio Communication by Scattering from Meteoric Ionization," Technical Report no. 57, Electronics Research Laboratory, Stanford University, Stanford, Calif.; 1952.

density trails, rate changes other than those predicted by the Lovell-Clegg theory may be obtained for radars with different over-all sensitivities. Such differences in sensitivity may be caused by inequalities in P_R, P_T, G_R, G_T, or R as well as by wavelength changes. Lovell used the expression "equivalent sensitivity" in his statement concerning the increase in echo rate for radars on wavelengths longer than about 6 meters. In the absence of a more complete definition, this term is interpreted as referring to radars with the same ratio of transmitted power to minimum detectable power at the receiver input terminals, and having antennas of identical dimensions in wavelengths. Such a definition does not include the reflection properties and range of the target, or the absolute capture area of the receiving antenna. These factors are included in the definition of system sensitivity used here, however, so that the sensitivity may be thought of in terms of the electron line density only.

Previous explanations of echo rate changes with wavelength have been based upon various proposed relationships between the scattering properties of the trails and the radio wavelength.[3,5] Such an approach was deemed necessary because experiment and available theory were not in agreement. The extension of the theory to include the high-density trails and the effects of meteoric velocity and initial trail size, however, appears to obviate the necessity of assumptions of this kind. It should be pointed out that the two-column trail model[5] was designed to explain certain apparent differences between observations made at Stanford University on 13 meters and at the University of Manchester on 4 meters. Recently, the English investigators have indicated that their original line density measurements were in error by a factor of about two powers of ten,[6] so that there is no longer any disagreement in amplitude measurements at the two wavelengths. In addition, the apparent discrepancy in polarization measurements made at the two wavelengths has been reconciled by the recent re-evaluation of their experimental results which has been made by the workers at Manchester.[13,14]

While it is believed that the explanations given here are the principal causes of the observed echo rate variations, it should be added that certain second order effects are expected to be due to wavelength changes. As mentioned by McKinley, more trails which do not present a perpendicular point to the transmitter-receiver site may be detected on the longer wavelengths than on the short wavelengths because the off-perpendicular echo power amplitude varies as λ^4 as compared to λ^3 for the normal echoes. However, it appears that an even more important consideration results from the relation between echo duration and wavelength. It has been well established that the duration of meteor echoes is proportional to λ^2. Theory indicates that only about 5 per cent of the meteor trails are initially oriented to present a perpendicular to the transmitter-receiver site and thus produce a strong echo.[12] However, due to upper atmosphere turbulence, the columns of ionization are contorted so that a trail which initially is not oriented to produce a strong reflection, may later have a portion of its length favorably positioned. The longer the trail persists at a size (measured in wavelengths) and density capable of giving an observable reflection when properly oriented, the greater the likelihood of obtaining such an echo. Thus, on the longer wavelengths, some increase in echo rate due to these distorted trails is expected.

Acknowledgments

The author gratefully acknowledges the helpful discussions and suggestions of Professors O. G. Villard, Jr. and L. A. Manning, and Dr. A. M. Peterson.

[13] J. A. Clegg and R. L. Closs, "Plasma oscillations in meteor trails," *Proc. Phys. Soc.* (London), vol. 64, pp. 718–719; 1951.

[14] R. L. Closs, J. A. Clegg and T. R. Kaiser, "An experimental study of radio reflections from meteor trails," *Phil. Mag.*, vol. 44, pp. 313–324; 1953.

A Statistical Survey of Atmospheric Index-of-Refraction Variation

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Summary—**This paper presents a statistical survey of index-of-refraction variations as recorded by an airborne microwave refractometer. Scales and intensities of the index variations are given, as well as the parameter $\overline{\Delta N^2}/l$, for data taken over southwest Ohio during summer months and over the Pacific Ocean off the west coast of Washington in August and of California in October. Heights from 2,000 to 25,000 feet, msl, were considered with most of the data taken between 2,000 and 12,000 feet. Approximately 1,200 samples taken on 34 flights were analysed. The composite of the data gave the following median values:**

Index Scale = 130 feet

Index Intensity = 0.3 N

$$\frac{\overline{\Delta N^2}}{l} = 7 \times 10^{-4} N^2/\text{ft}^*$$

Introduction

SINCE the introduction of the theory of tropospheric radio wave propagation by scattering by Booker and Gordon[1] there has been a need for experimental data on the scale and intensity of index of refraction variation. Recent developments of an airborne atmospheric refractometer[2] have made possible the measurement of rapid changes in the refractive index of the atmosphere.

Under the sponsorship and with the cooperation of the Radiation Laboratory of Wright Air Development Center, a number of refractive-index soundings were made in the general vicinity of the Wright-Patterson Air Force Base in southern Ohio during the summer of 1952. Under the sponsorship of Cambridge Air Force Research Center, and with the cooperation of this center and the Air Defense Command, refractometer soundings were taken off the west coast of Washington in August 1952 and of California in October 1952. Although these data were taken primarily for index profiles, they can be conveniently used to obtain scales and intensities of index variations.

Method of Detailed Calculations

The original data used were recorded on Esterline-Angus graphical records with traces similar to those shown in Fig. 1. In order that large scale changes would not obscure small ones, a smooth curve was drawn by eye through the sample of data to be considered as shown in Fig. 1. This smoothing process eliminated any scales larger than about 1,200 feet.

The deviations from such mean lines were measured and these data were used to obtain autocorrelation functions and the rms value of the variations.

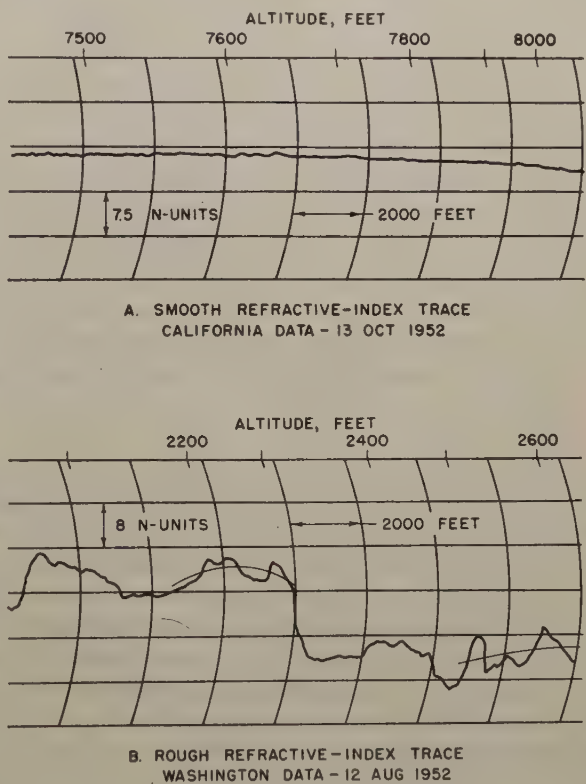

Fig. 1—Sample refractive index traces.

Method of Approximate Calculations

The exact calculations described in the previous section were so time-consuming that a comprehensive survey of data by this method would have been almost impossible. For this reason, an approximate method was used.

In this approximate method, the graphical data were prepared exactly as for the more detailed calculations. It was assumed that the variations were sinusoidal and the intensity was taken as 0.707 times the average peak value. The scale defined as the 0.5 point of the autocorrelations was approximated by taking 1/6 of the average period of the fluctuations.

* The Index Intensity ($\sqrt{\overline{(\Delta N)^2}}$) is the root mean square of the deviation of N from its average value and the Index Scale (l) is the distance at which the autocorrelation function of ΔN drops to 0.5. N is related to the index of refraction (n) by $N=(n-1)\times 10^6$.

[1] H. G. Booker and W. E. Gordon, "A theory of radio scattering in the troposphere," Proc. I.R.E., vol. 38, pp. 401–412; 1950.

[2] C. M. Crain and A. P. Deam, "An airborne microwave refractometer," *Rev. Scientific Instruments*, vol. 23, pp. 149–151; 1952.

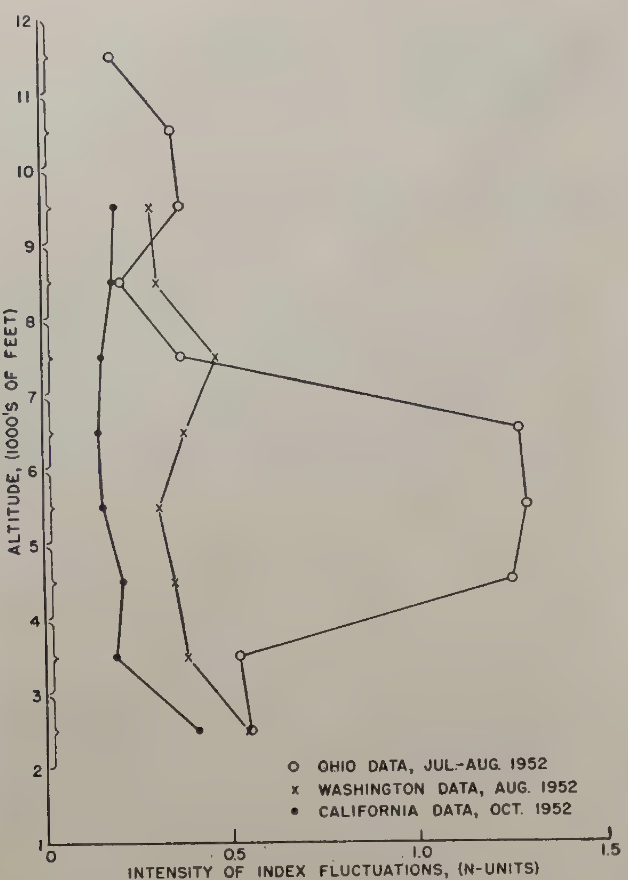

Fig. 2—Profiles of mean intensity over 1,000-foot altitude intervals.

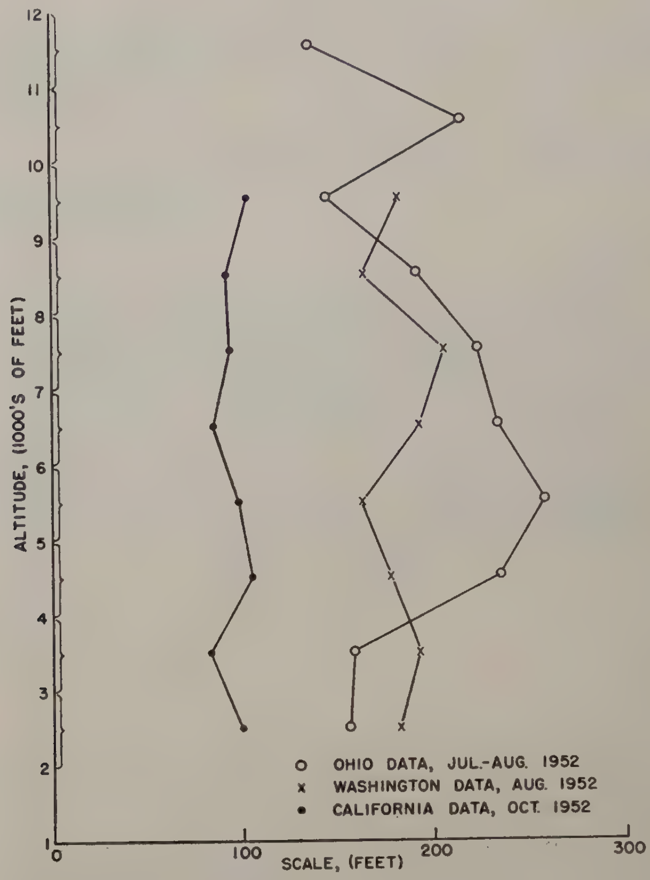

Fig. 3—Profiles of mean scale over 1,000-foot altitude intervals.

A comparison of the intensities and scales as determined by the more detailed and by the approximate method showed remarkably good agreement.

By using this approximate method it was possible to examine approximately 1,200 samples taken from 34 flights. Data from a number of other flights with different scale ranges were examined and found to evidence no major difference in characteristics of the index scales and intensities.

Statistical Distributions of Scale and Intensity

Statistical distributions were determined for each thousand-foot interval between 2 and 12 thousand feet and for the entire interval. The median values of intensity and scale as functions of elevation are shown in Fig. 2 and Fig. 3. Composite distribution curves for the three locations are shown in Fig. 4 and Fig. 5.

Trends in Intensity—Height Data

Generalities regarding the characteristics of the data are difficult, as shown by the classifications of the intensity-height curves shown in Fig. 6. This classification included the data from all three heights. It appears, however, that there is no continuous variation of intensities greater than 0.2 except in the first 1000 feet above the surface or near some cloud or inversion layers.

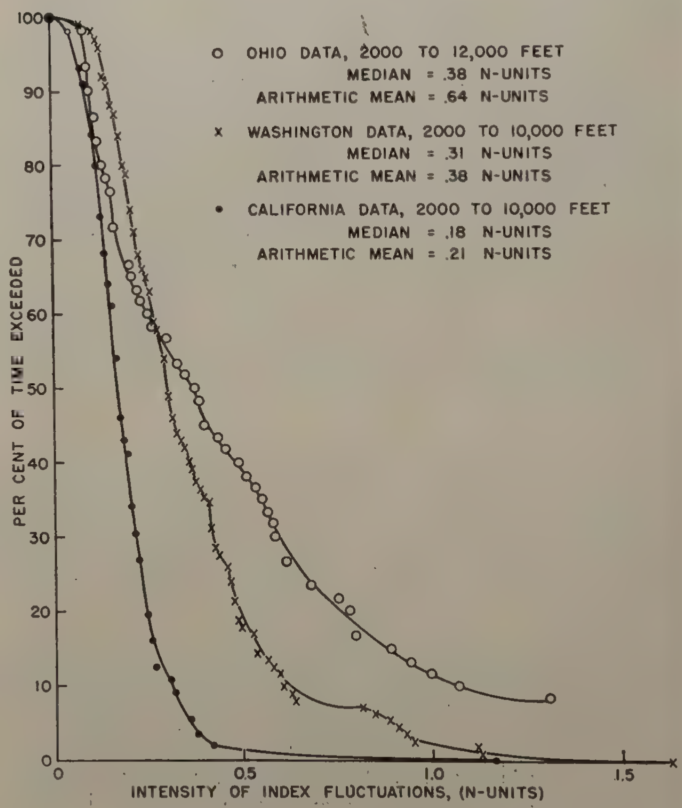

Fig. 4—Over-all intensity distributions.

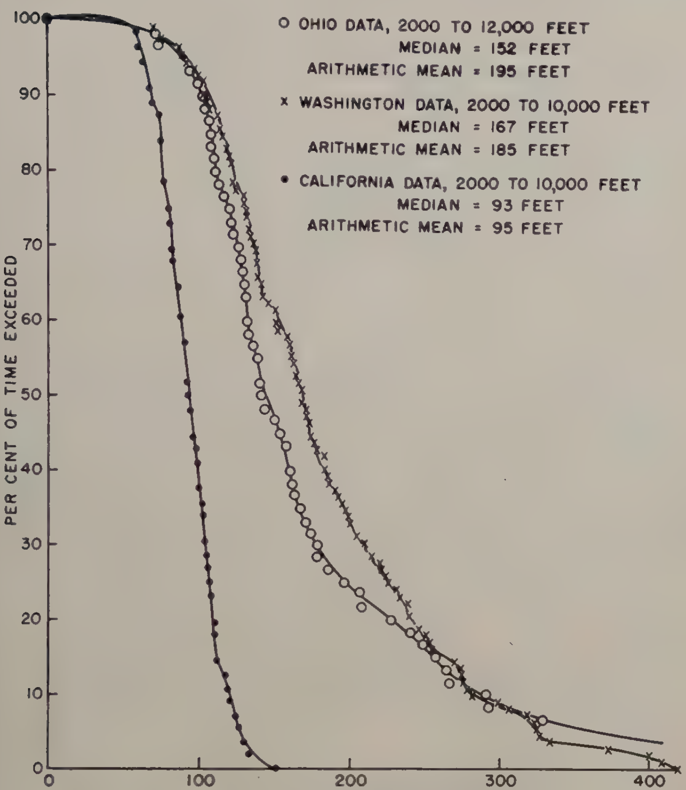

Fig. 5—Over-all scale distributions.

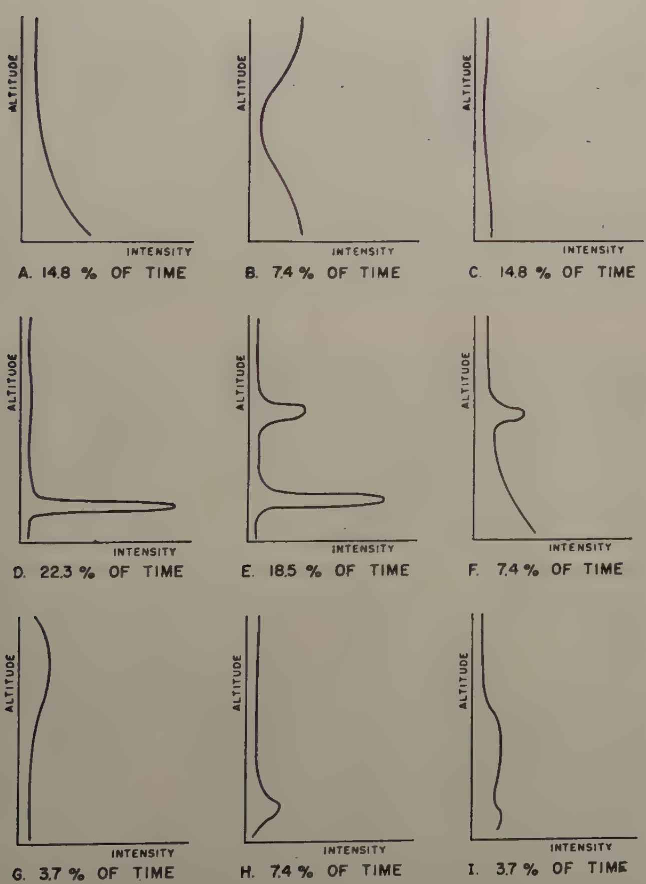

Fig. 6—Shapes of intensity profile trends and per cent of time each occurred.

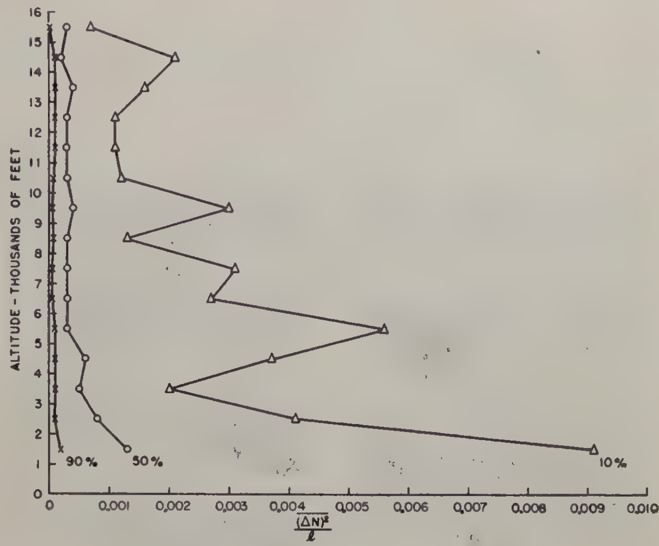

Fig. 7— $\frac{\overline{\Delta N^2}}{e}$ based on 1,200 samples.

Value of Parameter $\overline{\Delta N^2}/l$

In the scattering theory proposed by Booker and Gordon [1], the strength of the scattered signal is found to be proportional to $\overline{\Delta N^2}/l$ for off-beam scattering when the scale of index is large compared to the wavelength. Probability distribution curves were plotted for each 1,000-foot interval between 2 and 12 thousand feet and the values exceeded 10, 50, and 90 per cent of the time were obtained from these graphs. The values plotted as a function of altitude are shown in Fig. 7.

Data for Elevations Above 12,000 Feet

Approximately 100 soundings have been made at the various sites previously mentioned, in which the maximum altitude was 15,000 feet. For those soundings the refractometers were operated with scales in the 50–80 N-unit range, with a resulting meter vibration "noise" level of the order of .2 N-unit for all data except the southwest Ohio data, where the noise level was less than .1 N-unit. Visual survey of these data indicated that very rarely was one able to find any fluctuations above about 12,000 feet which could be separated from the noise level, and never were the fluctuation magnitudes appreciably greater than noise level.

Some 20 soundings have been made in the southwest Ohio vicinity to altitudes of 25,000 feet or more. Examination of the recording for two of these soundings have revealed no measurable fluctuations associated with scales of less than 100 feet above 15,000 feet.

The Propagation Unit at the Aircraft Radiation Laboratory has made a flight to 25,000 feet during which data were obtained on a recorder having a time constant of the order of .01 seconds, and using a scale of approximately 1 N-unit per inch of deflection. The results of the flight were not completely satisfactory as a peak to peak "noise" level of near 0.5 N-unit existed; however, a study of the data has indicated no measurable index fluctuations above 9,000 feet. These data were

obtained April 7, 1953 near Dayton, Ohio. Fig. 8 shows samples of the recorded data. (The noise level was determined by closing off the air flow around the sampling cavity during flight.)

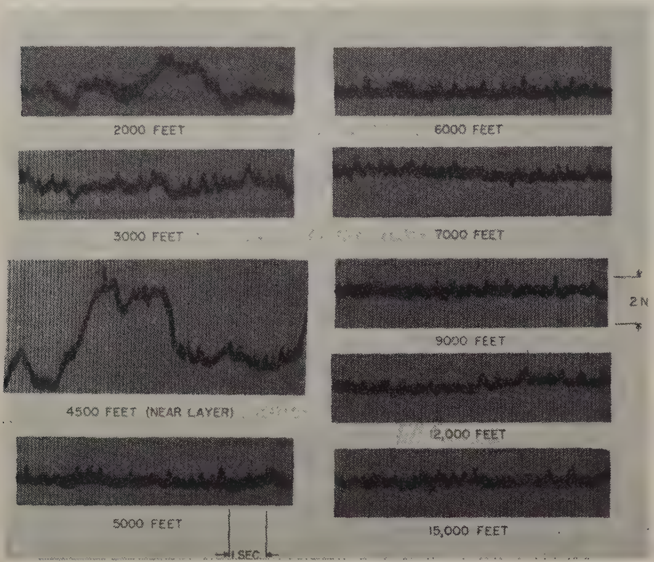

Fig. 8—Index of refraction variations obtained with a high frequency response recorder.

Discussion of the Recording Meter Response

Some doubt may exist as to whether or not the Esterline-Angus meter used to record all the data reported in the statistical summaries had adequate frequency response to follow accurately the index fluctuations encountered. The response of the refractometer metering amplifier as recorded on the Esterline-Angus meter was down to 0.7 at 0.8 cycle per second and down to 0.2 at 3 cycles per second. Thus with a plane speed near 200 feet per second, it is obvious that if fluctuations having a scale of this order or less are present they will be recorded with reduced amplitude or perhaps missed completely. A study of the frequency distribution of the index recordings obtained on sensitive scales (7.5 N-units full scale on the Esterline-Angus meter) indicates that the Esterline-Angus response is adequate at altitudes of hundreds of feet above the earth's surface. This conclusion has been tentatively verified by the data recorded on the high-speed recorder as shown in Fig. 8. Additional measurements with high-speed recorders and sensitive index scales are contemplated in the near future.

Electrically Small Antennas and the Low-Frequency Aircraft Antenna Problem

J. T. BOLLJAHN†, SENIOR MEMBER, IRE, AND R. F. REESE†

Summary—**This paper is concerned with the properties of antennas which are small relative to their operating wavelength. A brief analysis based upon quasi-static principles is presented, and two experimental procedures suggested by the nature of the analytical results are described. The application of these experimental procedures is illustrated with examples of measurements made in connection with the design of low-frequency aircraft antennas.**

Introduction

ANTENNAS which are electrically small are notably inefficient, and their use is generally limited to applications in which the space available for antennas is too small to permit the use of resonant-size antennas. Electrically small antennas find extensive application, however, in the field of long-range navigational aids for aircraft. Here, the requirements for reliability and low attenuation of the transmissions from the ground stations make it necessary to use wavelengths many times larger than the major dimensions of most of the aircraft receiving the transmissions. It follows that the airborne receiving antennas, which consist in part of the airframes themselves, fall into the "electrically small" category.

When concerned with low-frequency antenna design problems, the antenna engineer finds his requirements to be particularly exacting because of the inherent limitations of such antennas, and because his standard measuring equipment is largely unsuited to the task. This paper presents an analysis which is intended to clarify certain aspects of the operation of such antennas and presents a description of measuring techniques which may be used in their design.

Quasi-Static Fields

Let us consider the problem of the diffraction of a plane electromagnetic wave by a perfectly conducting

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body S. The total electric and magnetic fields, including the incident and scattered field components, satisfy Maxwell's equations

$$\left.\begin{aligned} \nabla \times E &= -j\omega\mu H \\ \nabla \times H &= j\omega\epsilon E \end{aligned}\right\}, \tag{1}$$

with the boundary conditions

$$\left.\begin{aligned} n \times E &= 0 \\ n \cdot H &= 0 \end{aligned}\right\} \text{ on } S. \tag{2}$$

If only the fields in the vicinity of S are considered, and if the radian frequency ω of the incident wave is made very small (i.e., if λ is made very large relative to the dimensions of the region under consideration), then the right-hand members in Eq. (1) may be neglected and the resulting approximate field equations are

$$\left.\begin{aligned} \nabla \times E &= 0 \\ \nabla \times H &= 0 \end{aligned}\right\}. \tag{3}$$

These are the equations of electrostatics and magnetostatics, and to this order of approximation the field solutions for dynamic problems may be derived from the corresponding static solutions E_0 and H_0 by writing

$$\left.\begin{aligned} E &= E_0 e^{j\omega t} \\ H &= H_0 e^{j\omega t} \end{aligned}\right\}. \tag{4}$$

The appropriate static fields to use in (4) are those which satisfy the boundary conditions expressed in (2) and which have directions and orientations approaching those of only the incident plane wave at points remote from S where the scattered field is small. As long as the frequency of the incident wave is sufficiently low to preclude resonance effects in the scatterer, the electric and magnetic fields near the scatterer are simply those given by the static field solutions, but having a time variation which is synchronous with that of the impressed field.

It is usually convenient to express the static fields in terms of the corresponding electric and magnetic scalar potential functions, $E_0 = -\nabla\phi_e$ and $H_0 = \nabla\phi_m$, where the potential functions satisfy the boundary conditions

$$\left.\begin{aligned} \phi_e &= \text{constant} \\ \frac{\partial \phi_m}{\partial n} &= 0 \end{aligned}\right\} \text{ on } S. \tag{5}$$

It should be remarked that the boundary conditions discussed so far are not in general sufficient to define ϕ_m uniquely. For multiply-connected scattering objects (i.e., objects having closed conducting loops) it is necessary to add the condition that no magnetic flux shall link a closed conducting loop. The significance of this additional condition will be considered further in a later section; it is not, however, of primary importance, since most of the airframes of interest are simply connected surfaces.

Electric Field Solutions

Suppose that the scatterer discussed above is an antenna consisting of two elements of arbitrary shape with a short circuit between the feed terminals. Placing the antenna in a uniform electrostatic field would result in a redistribution of the charge on the system so that charges of $+q$ and $-q$ respectively would appear on the two antenna elements. This is the static situation presented in the preceding section, and the electric field about the antenna is the electrostatic field E_0. For the low-frequency dynamic problem, it follows that the current flowing through the short-circuited terminals of the antenna is $j\omega q$. The magnetic field solution need not be considered in evaluating the short-circuit terminal current value since all currents on the conducting surface which are accounted for in the magnetic field solution are solenoidal and contribute nothing to the net terminal current.

The magnitude of the induced charge q in the static problem is, of course, dependent upon the orientation of the antenna in the impressed field just as the short-circuit terminal current in the dynamic problem depends upon the orientation of the antenna in accordance with its radiation pattern. As a consequence of the quasi-static nature of the electrically-small antenna problem, the radiation pattern will be that of an elementary dipole. If the antenna in question has been designed to have no dipole moment, it is readily shown that the induced charge in this experiment will be zero for any orientation of the antenna.

It is convenient to deal with a parameter called the equivalent area a of the antenna which is defined as

$$a = \frac{q_{\max}}{\epsilon_0 E_i}, \tag{6}$$

where E_i is the field intensity of the incident wave (or of the impressed electrostatic field), $q_{\max}$ is the value of induced charge when the antenna is oriented so as to maximize this charge, and $\epsilon_0 = 1/36\pi \times 10^{-9}$ farad/meter. In terms of the equivalent area, the maximum value of short-circuit terminal current in the small receiving antenna may be written as

$$I_{so} = j\omega\epsilon_0 a E_i. \tag{7}$$

Considering the two forms of the equivalent circuit of the receiving antenna shown in Fig. 1, it is seen that the equivalent area serves, in the equivalent current generator circuit, a function comparable to that served by the parameter l_e (effective length) in the more familiar voltage generator circuit. Both are constants of the antenna which are proportionality factors between the incident field amplitude and the level of excitation of a circuit connected to the antenna terminals. While the equivalent voltage generator circuit is particularly convenient to use for thin wire antennas because of the simple relationships between l_e and the

physical dimensions of such antennas,[1] the factor a is simpler to calculate or estimate for many other forms of antenna elements. In the equivalent circuits of Fig. 1,

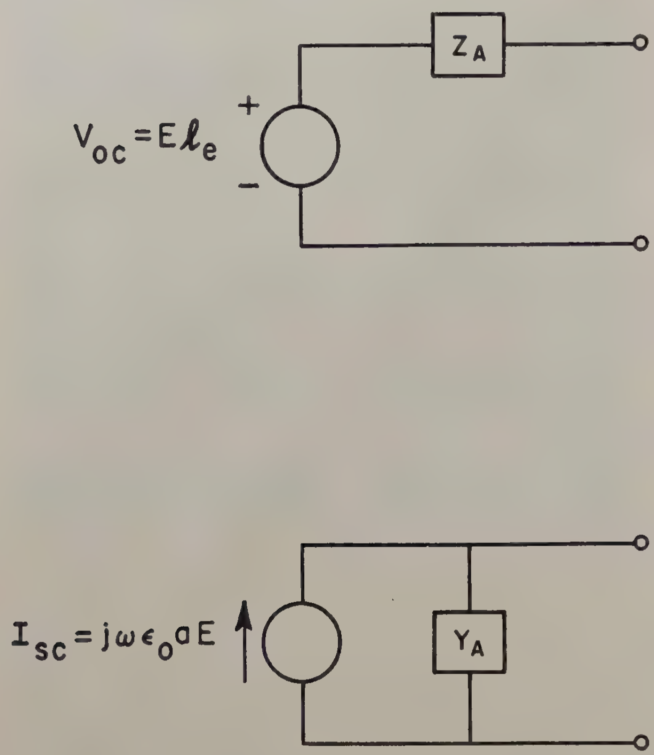


Fig. 1—Equivalent circuits of receiving antenna.

if the antenna impedance is taken as a pure capacitive reactance, as is customary in dealing with the circuit aspects of electrically small antennas, it is readily shown that l_e and a for a given antenna are related through the expression

$$\epsilon_0 a = l_e C_A, \tag{8}$$

where C_A is the capacitance of the antenna. Figs. 2, 3, 4, and 5 show calculated values of a for various types of antennas for which calculations of l_e would be extremely difficult. The antennas illustrated in these figures are unbalanced elements working against ground. The same factors apply to the corresponding balanced systems. From Fig. 2 it is noted that the equivalent area of an annular slot antenna is simply the area enclosed by the slot, assuming that the slot width is small relative to the transverse dimensions of the antenna.

The discussion thus far has been concerned entirely with receiving antenna properties and, indeed, most practical antennas operating in the quasi-static domain are receiving antennas. It is of interest, however, to note that the radiation conductance of such an antenna, a quantity which is significant only for the dynamic problem, may be expressed in terms of the parameter a which was defined in terms of the electrostatic behavior of the antenna in receiving. This expression may be derived using the reciprocity relationship

$$G = \frac{4\pi A}{\lambda^2}, \tag{9}$$

where G (antenna gain) $= 1.5$ for any antenna having a simple dipole radiation pattern and $A =$ receiving cross section. Expressing the antenna admittance as $g_a + jb_a$ and, with the aid of the equivalent current generator circuit, calculating the power delivered to a conjugate termination, it is found that

$$A = \frac{k^2 a^2}{4\eta g_a}, \tag{10}$$

where $\eta = 120\pi$ ohms, and

$$k = 2\pi/\lambda$$

Substituting this expression for A into (9) gives

$$g_a = \frac{k^4}{6\pi\eta} a^2. \tag{11}$$

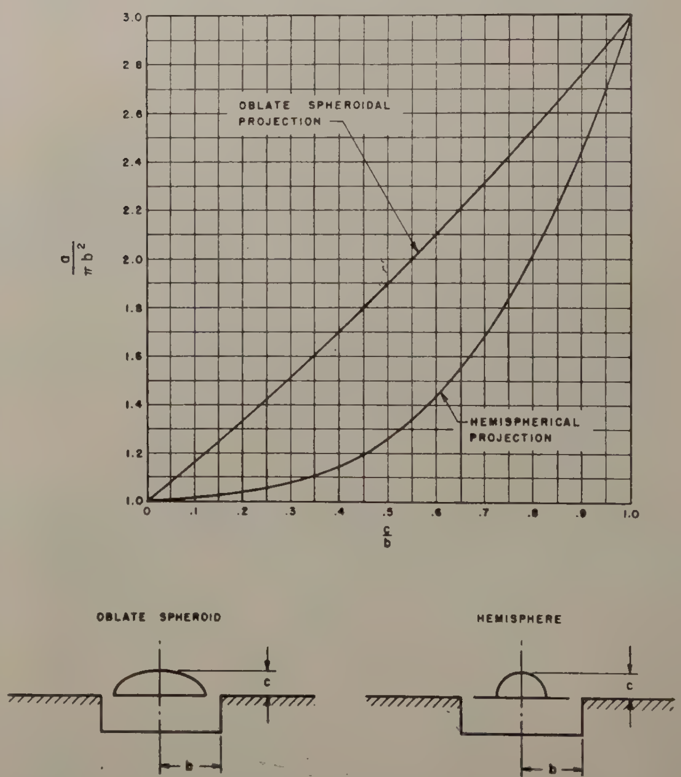


Fig. 2—Ratio of equivalent areas for projecting and flush antennas with same base area.

This equation holds for an antenna in free space; the value of g_a must be double for image-plane systems such as those shown in Figs. 2 through 5. A similar relationship between the effective length and radiation resistance of a small antenna may be calculated in a like manner.

[1] For example, the effective length of a short linear center-fed wire antenna is half the length of the antenna. The same antenna with end-loading elements added has an effective length equal to its physical length.

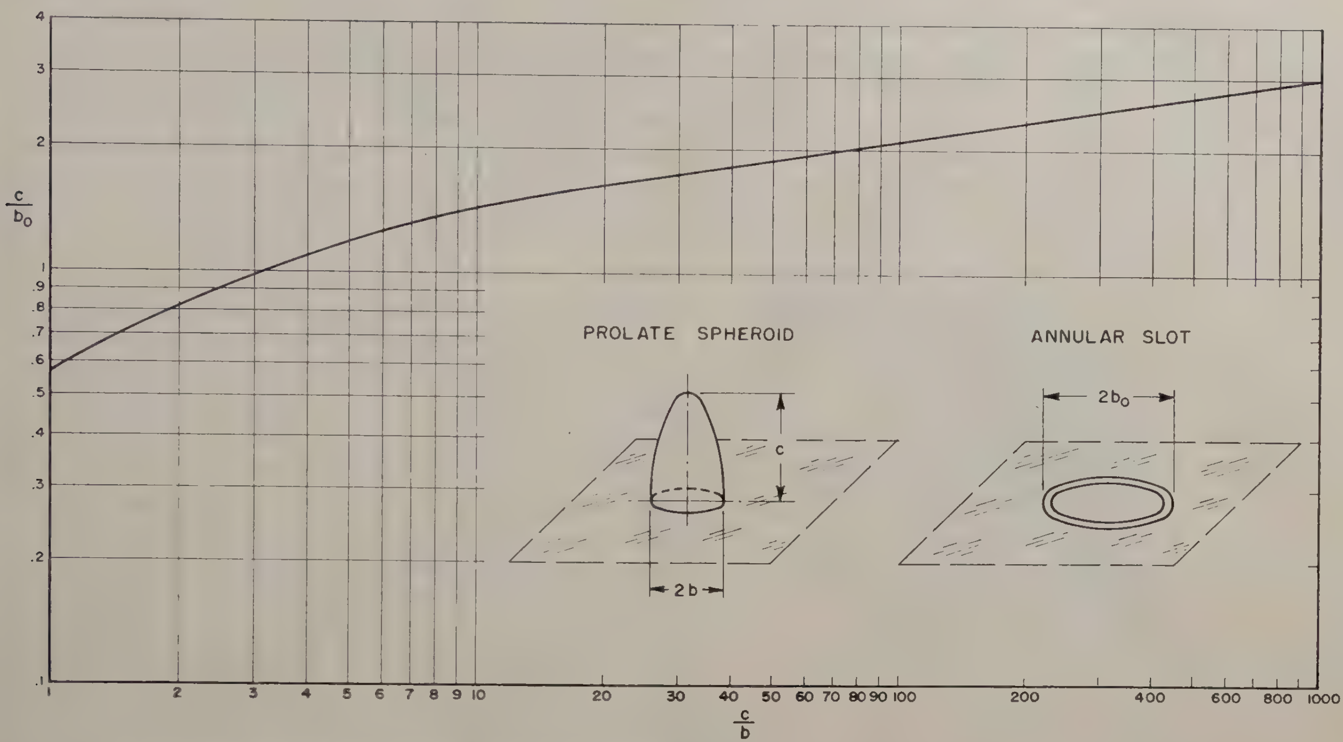


Fig. 3—Comparison of dimensions of prolate spheroidal and annular slot antennas having same equivalent areas.

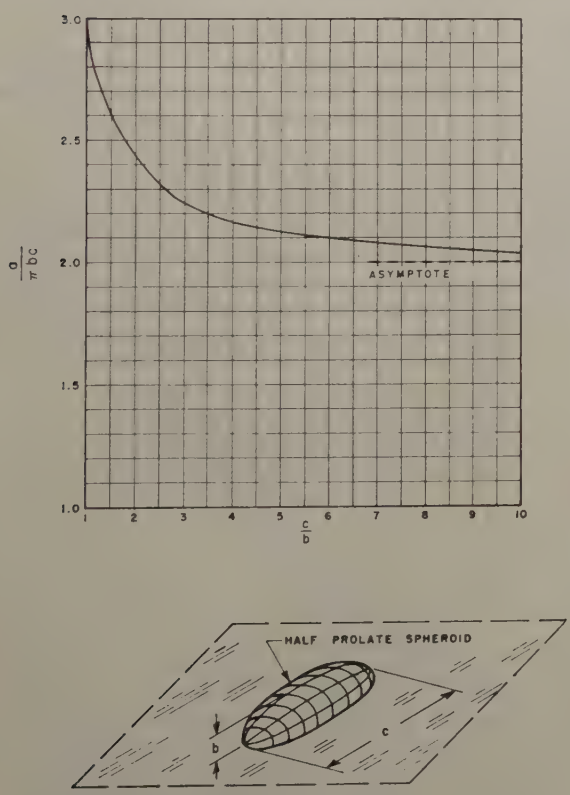


Fig. 4—Normalized equivalent area for half prolate spheroidal antenna.

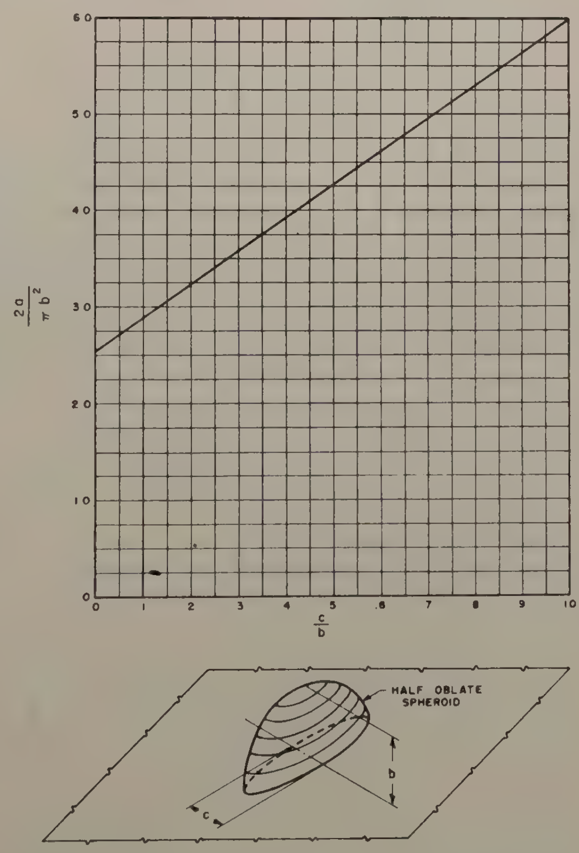


Fig. 5—Normalized equivalent area for half oblate spheroidal antenna.

Electric Dipole Measurements

An electrostatic measuring technique, by which the induced charge on one element of the antenna due to a uniform impressed field is measured directly has been developed for the study of electrically small antennas of the electric dipole type. The uniform field is produced between the plates of a large parallel plate capacitor equipped with guard rings to eliminate fringing of the field (Fig. 6). A scale model of the antenna of interest is supported in the uniform field on an insulating shaft. In

this case, a model aircraft is used with a small antenna element of arbitrary shape mounted at the desired position. The antenna element to be tested is connected conductively to the model airframe in such a manner that it can be pulled free of the model by means of a fine, insulating string. This is done while the impressed field is present so that the charge induced by the field

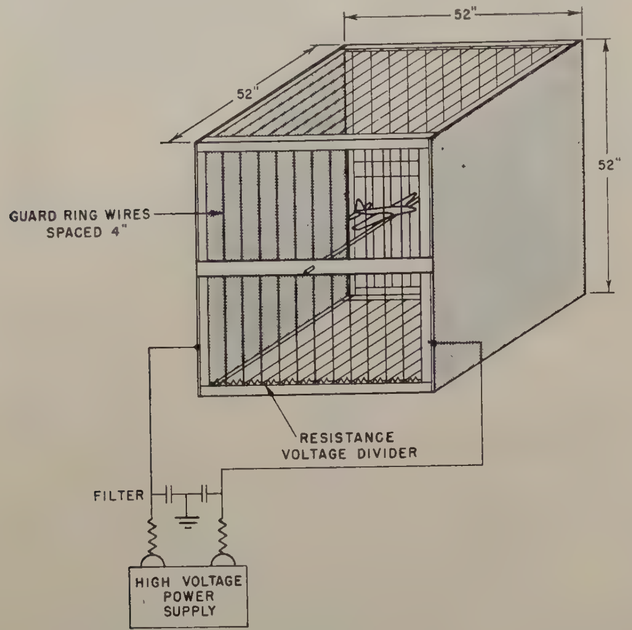
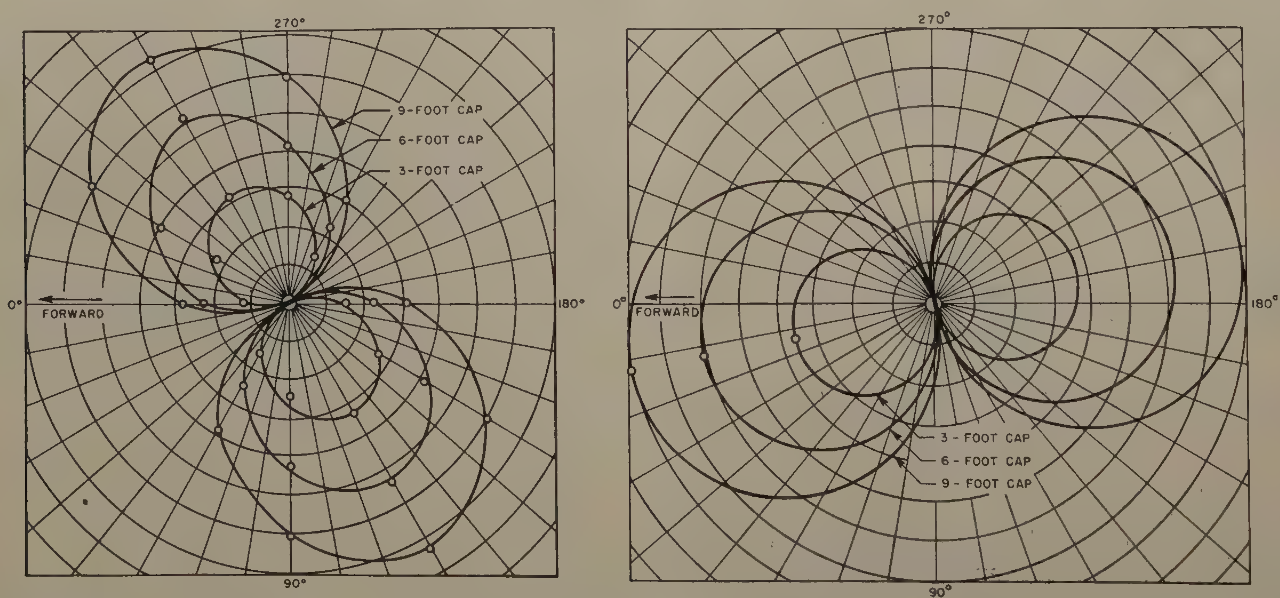


Fig. 6—Electrostatic cage for electric dipole measurements.

on the antenna element is carried away from the system. The quantity of induced charge is measured by lowering the model antenna element into a calibrated electrometer. By repeating the measurement for several different orientations of the aircraft model it is possible to determine the radiation pattern of the antenna-airframe system. Since the pattern will always be that of a simple dipole, only its orientation relative to the aircraft line of flight and the actual quantity of induced charge corresponding to maximum response are required to specify the performance of a particular antenna (except for the antenna capacitance, which must be determined by a separate measurement). A knowledge of the intensity of the impressed field permits a direct evaluation of the equivalent area by means of (6).

A simple physical interpretation of the equivalent area of an antenna may be made with reference to this measuring procedure. With the system oriented so that maximum charge is induced on the antenna, if it were possible to trace all of the electric field lines terminating on the antenna back to their other ends on the plate of the uniform field capacitor, it would be found that the area encompassing these field line terminations would be equal to equivalent area of the antenna.

An example of the type of measured results obtained is shown in Fig. 7. These plots show the low-frequency radiation patterns and equivalent areas of three antennas formed by isolating different length sections of the vertical stabilizer of a DC-4 aircraft, and using the isolated section and the remainder of the aircraft as the two elements of the antenna. It is seen that the radiation pattern of such an antenna system is essentially independent of the size of the isolated section. It is tilted from the line of flight as would be expected due to the superposition of the vertical dipole moment resulting from currents in the vertical stabilizer and horizontal dipole moment resulting from currents in the fuselage if the antenna were used as a transmitting antenna. Equivalent area values in Fig. 7 apply to the full-scale system. They have been calculated from the corresponding model values by multiplying the latter by the square of the scale factor. Vertical stabilizer antennas of this type are of interest as Loran receiving antennas.



$a = 130$ sq. meter for 9 ft. cap.

Fig. 7—Low frequency radiation patterns of wing-cap and tail-cap antennas on DC-4 aircraft.

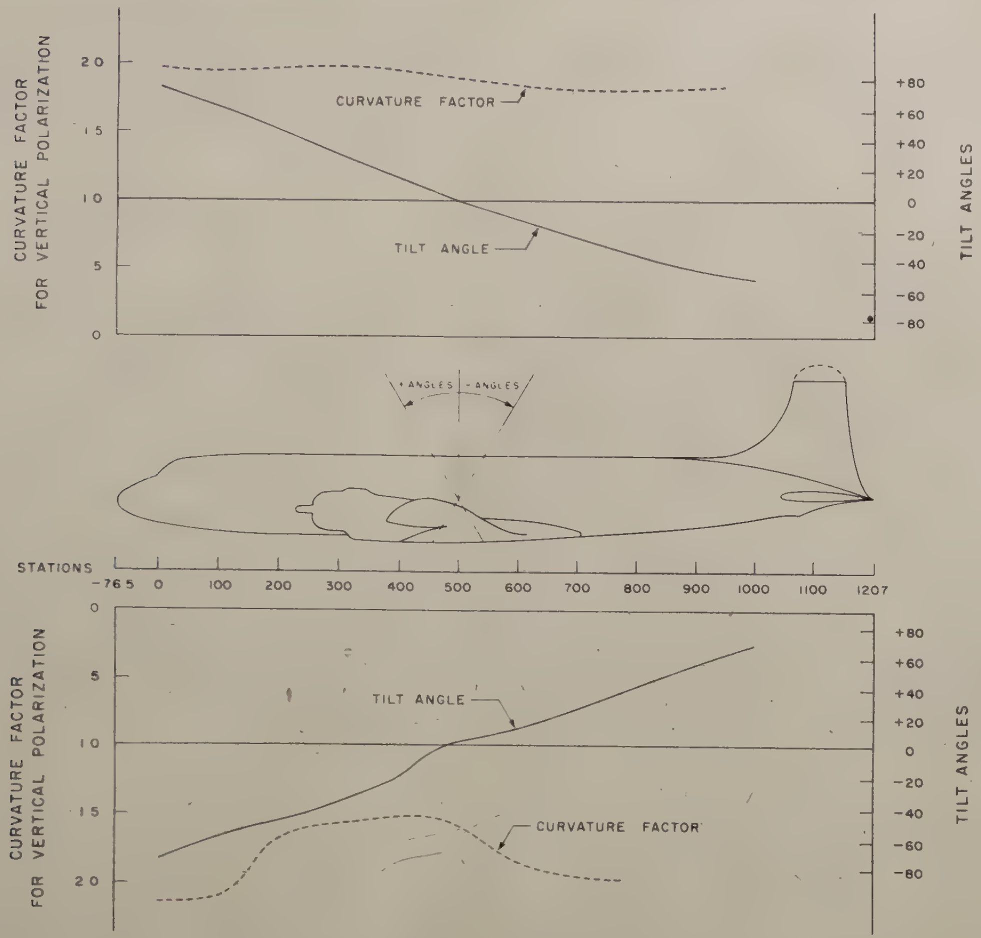


Fig. 8—ADF sense antenna location study on DC-6A aircraft.

Another antenna type for which this evaluation technique is applicable is the radio-compass sense antenna. The operational use of this antenna is such that it is highly desirable to have its dipole pattern oriented vertically. The antenna elements used as sense antennas are relatively small compared with the airframe dimensions, so that pattern is governed largely by the location of the antenna on the airframe rather than by the design of the antenna element proper.

Model pattern measurements can be made, therefore, using a small antenna element of any convenient size and shape, and the results are valid for whatever type of sense antenna is to be used. Another factor of interest, which is also independent of the antenna configuration, is the fringing of the electric field due to the curvature of the airframe and the corresponding increase in the receiving sensitivity of an antenna mounted on the airframe over its value for the same antenna mounted on a flat ground plane. The factor by which the receiving sensitivity is increased is called the curvature factor, and it is determined from electrostatic cage measurements by observing the ratio of induced charge on the antenna when it is mounted first on the aircraft model and then on a flat ground plane.

The results of a study to determine curvature factors and tilt angles for various possible sense antenna locations on the top and bottom center lines of a DC-6 aircraft are shown in Fig. 8. It is noted that the ideal locations from the pattern standpoint occur at nearly the same fuselage station for either a top or bottom installation. The curvature factor for vertically polarized signals along the top center line of the fuselage is close to 2, which is the theoretical value for an infinite circular cylinder. The shielding effect of the wings reduces this factor somewhat for bottom locations in the region of the wing-root.

To complete the design of a sense antenna system, accurate data must be obtained on the effective length and capacitance of the antenna element to be used. Such data may be measured with the antenna mounted on a flat ground plane, and the effective length of the installed antenna may be calculated by multiplying the flat ground plane value by the appropriate curvature factor. Accurate flat ground plane measurements may be made on relatively large scale antenna models by mounting them on one plate of the electrostatic cage. The cage is energized with an audio-frequency voltage for such measurements, and the antenna response is measured by means of a high impedance voltmeter connected directly between its input terminal and the grounded plate. Corrections must be applied to the voltmeter reading to take account of the voltage division

between the antenna capacitance and the voltmeter input capacitance. Extensive studies of various types of flush sense antennas have been completed using this technique.

Magnetic Field Solutions

A treatment of the magnetic field solutions may be carried out which is closely analogous to that used in Section III for the electric field problem. However, this is recognized as a standard treatment of the small loop antenna problem. For example, in Figs. 2, 3, 4, and 5, the equivalent area a may also be interpreted as the area of single-turn, air-core loop antenna which has in each case the same open-circuit voltage as a single-turn loop around a high-permeability core of the shape indicated. Rather than tracing this analogy in detail, the remaining discussion will be concerned with a particular application of the quasi-static magnetic field solution, namely, the study of low-frequency loop bearing errors.

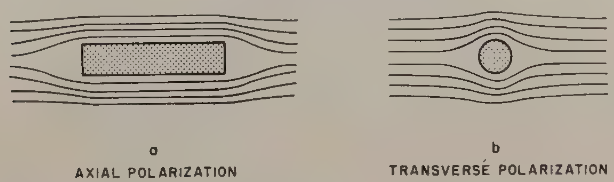


Fig. 9—Magnetic field distortion by a cylindrical conductor.

From the boundary condition on the magnetic scalar potential expressed in (5) it is seen that the distortion of the magnetic field lines near a small scattering obstacle is governed by the same laws as those which describe the distortion of the flow lines in the flow of a fluid past a similar obstacle. Fig. 9 illustrates the nature of this distortion near a cylindrical object for the two principal directions of the incident magnetic field (parallel to and perpendicular to the cylinder axis).

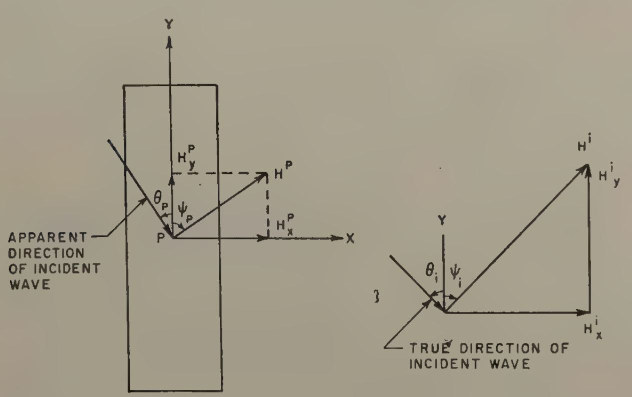


Fig. 10—Relationship between incident and local magnetic field.

It is of interest now to consider the behavior of the magnetic field at a point P near the surface of the cylinder as the incident field direction is rotated between these two principal directions. Because of the quasi-static nature of the problem, the local field at P caused by an incident field at an angle ψ_i (Fig. 10) may be calculated by resolving the incident field into its two components in the two principal directions, evaluating the two corresponding principal components of the local field, and adding these vectorially. Expressing the relationships between the amplitudes of the local and the incident magnetic fields for the two principal directions as

$$\left.\begin{aligned} H_x^P &= a_x H_x^i \\ H_y^P &= a_y H_y^i \end{aligned}\right\}, \tag{12}$$

it is readily shown that the following relationships hold between the local field and the incident field amplitudes and directions:

$$H^P = H^i\sqrt{a_x^2 \cos^2 \psi_i + a_y^2 \sin^2 \psi_i}, \tag{13}$$

$$\tan \psi_P = \frac{a_x}{a_y} \tan \psi_i. \tag{14}$$

Although the point P has been chosen close to the surface of the obstacle for this discussion, symmetry arguments show that general relationships of the form given in (12) hold for any point in the plane $x=0$ or $y=0$. For a general location it is necessary to use the more general relationships

$$\begin{aligned} H_x^P &= a_{xx}H_x^i + a_{xy}H_y^i \\ H_y^P &= a_{yx}H_x^i + a_{yy}H_y^i. \end{aligned} \tag{15}$$

If a small direction finder loop antenna is located at P, with its axis of rotation normal to the conducting surface at that point, it will indicate the direction of the incident wave to be 90° from the direction of H^P rather than the correct direction which is 90° from H^i. The relationship between the true bearing θ_i and the apparent bearing θ, where the angles θ are measured from the y axis (Fig. 10), follows from (14)

$$\tan \theta_P = \frac{a_y}{a_x} \tan \theta_i. \tag{16}$$

This is the well-known equation for the quadrantal bearing error of a low-frequency direction finding system.[2]

The constants a_x and a_y may be calculated in certain simple cases where the boundaries of the scattering obstacle coincide with a coordinate surface in one of the basic coordinate systems. It is then possible to find solutions to Laplace's equation which satisfy the boundary condition on ϕ_m in (5), and which reduce to the appropriate uniform field at large distances from the obstacle. For example, for a circular cylindrical obstacle such as that in Figs. 9 and 10, but having an infinite length, it is found that $a_x=2$, and $a_y=1$ at the surface. The prolate spheroidal obstacle is another case for which theoretical results may be obtained. Fig. 11 shows a plot of the calculated bearing deviation curve for a prolate spheroidal obstacle having a major-to-minor axis ratio

[2] R. Keen, "Wireless Direction Finding," Iliffe and Sons, Ltd., London; 1947.

of 4. Also shown is the ratio of the maximum response of a loop antenna near the scattering spheroid at the point indicated to the maximum response of the same loop in the absence of the scattering spheroid.

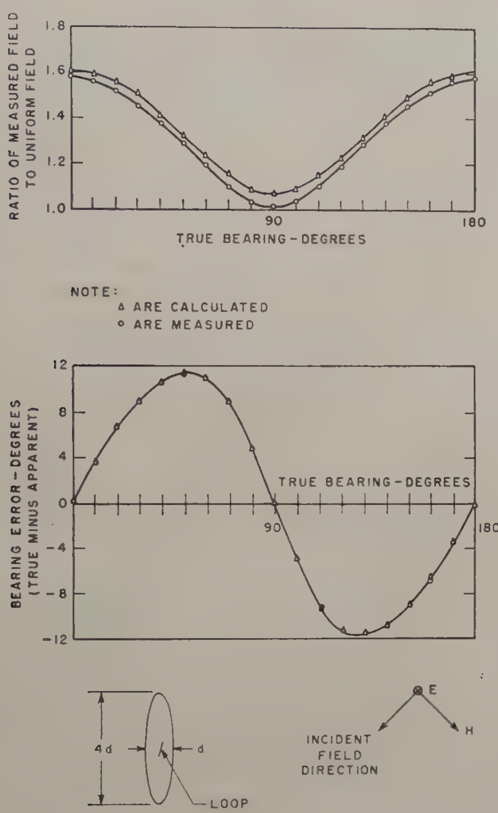


Fig. 11—Response and bearing error for a prolate spheroid.

Loop Antenna Measurements

For scattering obstacles of more practical interest, such as aircraft, it is not possible to evaluate the bearing error and the effect upon loop sensitivity analytically, and these factors are usually evaluated by means of tests on the full-scale system. The nature of the quasi-static magnetic field solutions suggest that an analog measuring technique may be used here. The analog system which appears most promising, and the one developed in connection with this study, employs non-conducting models of the scattering obstacles of interest in an electrolytic tank in which an initially uniform volume current may be established. The distortion of the current-flow lines (or electric field lines) caused by the non-conducting model is the same as the distortion of the low-frequency magnetic field lines caused by the full-scale conducting aircraft in flight. This is because the boundary condition on the electric scalar potential in the analog system is the same as that expressed by (5) for the magnetic scalar potential in the full-scale system.

A schematic diagram showing the essential components of the analog measuring system is given in Fig. 12. Audio frequency rather than direct current excitation is used in order to simplify the problem of amplifying the signal received on the balanced probe which simulates the loop and to avoid polarization effects in the electrolytes. The simulated loop antenna is a balanced voltage probe which samples the local electric field near the scattering object to determine its amplitude and direction. The probe shown in Fig. 12 is in the form of two conducting hemispherical elements. If these were shorted together to form a full conducting sphere it would cause the current flow lines in the electrolyte to converge into it in the same way that a sphere of high-permeability material would converge the magnetic field lines in the actual system. The total current through the shorted probe terminals is therefore analogous to the total magnetic flux through a spherical high-permeability core in the full-scale system. Since the latter quantity is in turn proportional to the open-circuit voltage induced in the loop antenna on the spherical core, it follows that quantitative information about the sensitivity of the full scale loop systems may be measured in the electrolytic tank. It may be shown by the same reasoning that the analog of an air-core loop is a voltage probe which resembles a parallel-plate capacitor with closely spaced plates.

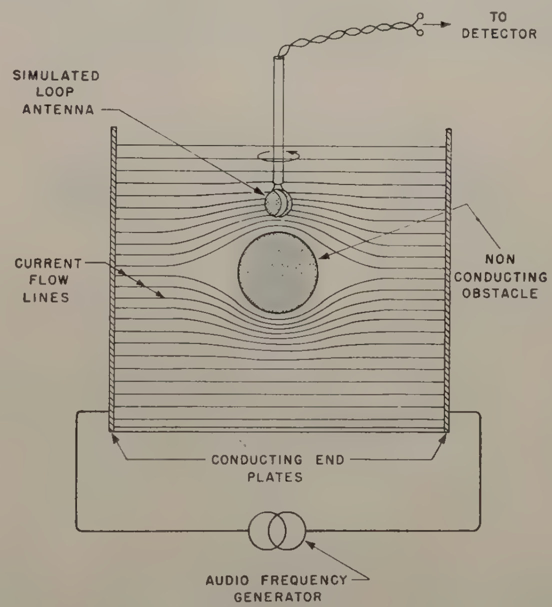


Fig. 12—Electrolytic tank for ADF loop antenna measurements.

For measurements on a particular system, the aircraft model and the simulated loop are supported in the 40-in. cubical electrolytic tank on separate vertical shafts which are mounted on a rotatable supporting plate located above the surface of the electrolyte (which is filtered tap water). The plate and aircraft model may be rotated relative to the impressed field direction without changing the position of the loop relative to the airframe. For any heading of the aircraft, the loop may be turned through a full 360° by turning its shaft while the supporting plate remains fixed. Although the models may be mounted to simulate various angles of climb,

dive or bank, the case of great interest, and that for which measurements are most easily made, is the case of level flight. The horizontal electric field in the tank corresponds, in this case, to the horizontal magnetic field in a ground-wave signal.

Bearing error measurements may be made by determining the orientation of the loop antenna which produces a null in the output signal for each of a series of aircraft headings. Alternatively, for loop locations on the fuselage centerline, symmetry considerations show that two measurements to obtain the relative sensitivity of the loop when the model is oriented first parallel to and then perpendicular to the impressed field direction suffice to specify the bearing error curve. These two measurements yield the ratio of the factors a_x and a_y discussed in the preceding section on loop antenna measurements, and the bearing error curve may be constructed with the aid of (16). One further measurement to give the response of the loop in the absence of the model may be made to determine the values of a_x and a_y separately.

Bearing error curves measured on a model of the DC-3 aircraft are shown in Fig. 13, together with corresponding full-scale measurements made in flight.[3] The excellent agreement achieved in this comparison and in other checks between theoretical and experimental results indicate a high order of accuracy for the analog measuring system.

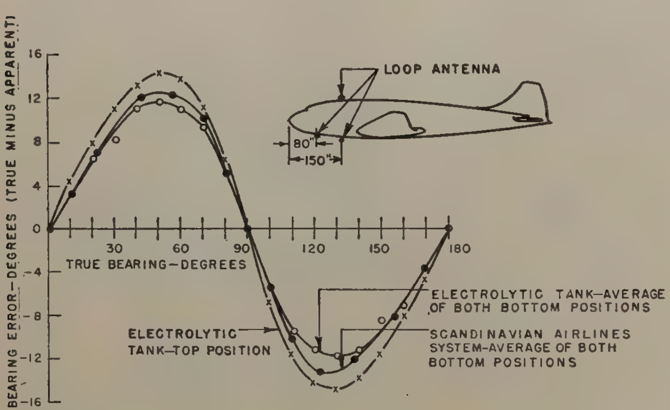


Fig. 13—ADF loop bearing error curves for DC-3 aircraft.

The electrolytic tank has been used in somewhat modified form to investigate other problems relating to aircraft loop antenna design. The loss of sensitivity of a loop antenna when it is placed in a conducting cavity, various methods of bearing error compensation, the accuracy of full-scale bearing-error measurements made with the aircraft on the ground, and the possibility of increasing loop senstivity by placing flush patches of high-permeability material nearby have been studied using the analog method.

It is of interest at this point to consider briefly the implication of the statement made in Section II limiting the application of the quasi-static approximations in the form used here to simply connected scattering objects. Let us suppose it is required to measure the magnetic field distortion caused by a small conducting toroid with its axis parallel to the impressed field. If such a conductor were simulated in the electrolytic tank by a dielectric toroid, the resulting current-flow pattern would look, in cross section, much like that due to two parallel cylinders with each cylinder producing a distortion pattern such as that shown in Fig. 9. This is clearly not the correct result, since all the current-flow lines which link the analog toroid represent magnetic flux threading the conducting toroid, while actually there can be no flux through the toroid. On further examination it is found that the field distortion observed in the electrolytic tank corresponds to that which would be caused by the toroidal conductor if it were cut so that currents could not flow around the closed loop. Similarly for any scattering objects containing closed conducting loops, the analog system yields results which portray the magnetic field as it would exist near the scatterer if the conductors were severed to eliminate circulating currents in these loops. The analog technique can not be applied, therefore, to the study of loop antennas on twin-boom aircraft or to the investigation of certain types of bearing error compensators which use corrector bars.

Conclusions

Quasi-static measuring techniques suitable for the measurement of the radiation pattern and receiving sensitivity of electrically small antennas of both the electric dipole and magnetic dipole types have been described. These techniques are rapid and simple in application and they yield results which are sufficiently accurate for many low-frequency antenna design problems. Some applications and limitations of these techniques in the field of aircraft antenna design have been discussed.

[3] These flight test results are used here through the courtesy of the Scandinavian Airlines System.

communications

Report of the Tenth URSI General Assembly *Sidney, Australia, August 11-24, 1952*

CHARLES R. BURROWS†, FELLOW, IRE

THE TENTH GENERAL ASSEMBLY of the International Scientific Radio Union (URSI) was held in Sydney, Australia, during the interval August 11–24, 1952. The hosts of the meetings were the Australian Government and several divisions thereof, the University of Sydney, and several Australian industrial organizations having an interest in the work of the Union.

The Assembly was attended by 322 individuals, of whom 54 were from countries other than Australia. Delegates from the following countries were present: Australia, Belgium, Canada, France, Great Britain, India, Italy, Macao, Morocco, Netherlands, New Zealand, and the United States. Representatives from the following international organizations were also present: International Radio Consultative Committee, International Union of Geodesy and Geophysics, International Union of Pure and Applied Physics, International Union of Chemistry, and the International Union of Biological Sciences.

The United States Delegation consisted of:

(1) Voting Delegates:

Dr. Charles R. Burrows, Head of the U. S. Delgation
Director, School of Electrical Engineering
Cornell University
Ithaca, New York

Dr. J. Howard Dellinger
Consultant, Radio Corporation of America
1625 K Street, N. W.
Washington, D. C.

Dr. Arthur H. Waynick, Secretary
Head, Electrical Engineering Department
Pennsylvania State College
State College, Pennsylvania

Mr. Francis J. Gaffney
Polytechnic Research and Development Co.
202 Tillary Street
Brooklyn 1, New York

Mr. Harold E. Dinger
Naval Research Laboratory
Washington 25, D. C.

(2) Delegates-at-large:

Dr. Harold I. Ewen
Harvard University
Cambridge, Massachusetts

Dr. William E. Gordon
School of Electrical Engineering
Cornell University
Ithaca, New York

Dr. John P. Hagen
Naval Research Laboratory
Washington, D. C.

Dr. Robert A. Helliwell
Department of Electrical Engineering
Stanford University
Stanford, California

† Cornell University, Ithaca, New York.

Mr. Martin Katzin
Naval Research Laboratory
Washington 25, D. C.

Dr. Laurence A. Manning
Radio Propagation Laboratory
Stanford University
Stanford, California

Dr. Millet G. Morgan
Thayer School of Engineering
Dartmouth College
Hanover, New Hampsnire

Mr. Alan H. Shapley
Central Radio Propagation Laboratory
National Bureau of Standards
Washington, D. C.

Dr. Samuel Silver
Division of Electrical Engineering
University of California
Berkeley, California

Dr. John B. Smyth
U. S. Navy Electronics Laboratory
San Diego 52, California

Dr. Roy C. Spencer
Electronics Research Division
Air Force Cambridge Research Center
230 Albany Street
Cambridge 39, Massachusetts.

Dr. L. C. van Atta
Hughes Aircraft Company
Culver City, California

The Canadian Delegation consisted of the following voting delegates:

Dr. D. W. R. McKinley, Chairman
National Research Council
Ottawa, Canada

Dr. J. C. W. Scott
Assistant Superintendent, Radio Physics Laboratory
Defense Research Board
Prescott Highway
Ottawa, Canada

Dr. G. A. Woonton
Professor of Physics
McGill University
Montreal, Canada

The meetings were held at the University of Sydney, with the Electrical Engineering Department serving as host. The Executive Committee meetings, attended by the head of the delegation from each country, and the Administrative Opening and Closure were presided over by Sir Edward Appleton, President of URSI. The scientific work of the assembly was carried out at meetings of the various commissions under the chairmanship of their presidents as follows:

Commission I	Radio Measurement Methods and Standards Dr. J. H. Dellinger, chairman
Commission II	Tropospheric Radio Propagation Dr. C. R. Burrows, chairman
Commission III	Ionsopheric Radio Propagation Sir Edward Appleton, chairman
Commission IV	Terrestrial Radio Noise Mr. J. A. Ratcliffe, acting for Dr. H. Norinder, chairman
Commission V	Radio Astronomy Dr. D. F. Martyn, chairman
Commission VI	Radio Waves and Circuits including General Theory and Antennas and Waveguide Prof. Dr. B. van der Pol, chairman
Commission VII	Electronics Prof. G. A. Woonton, acting for Dr. G. Lehman, chairman

The following general comments concerning the work of each Commission may be of interest: Progress was made towards the international exchange of radio standards. Considerable interest was evinced in determining the mechanism whereby tropospheric radio signals are transmitted over great distances, with regard to the meteorological mechanisms involved. There was considerable interest in long distance ionospheric propagation by, presumably, scattering mechanisms. The planning for cooperative measures to fill the serious gap in our knowledge concerning the world-wide distribution, intensity and frequency characteristics of terrestrial radio noise was carried out. The tremendous strides that have recently been made in the field of radio astronomy was indicated by the quality and quantity of the papers presented in this field. The American contributions as regards intergalactic hydrogen line emissions were noteworthy. The great advances being made in the studies of antennas and waveguides were made evident. The United States was inadequately represented in the field of electronics. This is indeed unfortunate in view of the outstanding work being done in this country in this field.

Several matters of more general interest might be mentioned. One of these was the establishment of a policy whereby issuance of special URSI reports will now be accelerated. These will comprise reports concerning matters of general interest to URSI, will be prepared by a small group of specialists in a given field, and will, in general, attempt to cover the subject matter in such a way as to outline the present status of the field

covered by the report. At the General Assembly it was decided that work on the following special reports would be undertaken:

Commission II	Propagation beyond the horizon Propagation within the horizon
Commission III	World morphology of ionospheric storms Radio detection of meteors Wave interaction in the ionosphere Summary of 1952 ionospheric eclipse results
Commission IV	Interstellar hydrogen Discrete sources in the galaxy Distribution of radio brightness on the solar disk.

Preparations are being made for the Geophysical Year 1957–58. Many suggestions concerning planning for the Year were outlined and a committee to advise the URSI representatives on the Geophysical Year Committee of the ICSU, Mr. L. V. Berkner and Dr. W. F. G. Beynon, was appointed under the chairmanship of Sir Edward Appleton.

Three special committees were appointed to prepare special reports for the Executive Committee:

(a) Finance Committee (in accordance with the Statutes)

Dr. R. L. Smith-Rose, Chairman
Dr. C. Aurell
Prof. B. D. H. Tellegen

This committee audited the treasurer's report.

(b) Publication Committee (to consider proposals from the United States and to compare them with the conclusions of the report drafted in 1951)

M. Laffineur, Chairman
Dr. J. H. Dellinger
Dr. D. W. R. McKinely

The committee recommended the publication of special reports, instead of the papers presented at the assembly, as described in more detail elsewhere.

(c) Statutes Committee (to consider the proposals of the Drafting Committee appointed in 1950)

F. P. LeJay, Chairman
Prof. M. Boella
Dr. Chas. R. Burrows

This committee reviewed the statutes of the URSI. The new statutes resolve the difficulties resulting from differences in the national organizations of the various countries adhering to URSI. They were approved.

The following were elected to office for 1952–54:

President:	Father P. LeJay (France)
Vice Presidents:	Dr. D. F. Martyn (Australia) Dr. C. R. Burrows (United States) Prof. B. D. H. Tellegen (Netherlands)
Secretary General:	Ing. E. Herbays (Belgium)
Treasurer:	Prof. C. Manneback (Belgium)
Chairman of Commission I	Dr. R. L. Smith-Rose (England)
Chairman of Commission II	Dr. C. R. Burrows (U.S.A.)
Chairman of Commission III	Sir Edward Appleton (England)
Chairman of Commission IV	Dr. J. A. Ratcliffe (England)
Chairman of Commission V	Dr. M. Laffineur (France)
Chairman of Commission VI	Dr. L. C. van Atta (U.S.A.)
Chairman of Commission VII	Prof. G. A. Woonton (Canada)
Honorary Presidents	Sir Edward Appleton (England) Dr. J. H. Dellinger (U.S.A.) Dr. B. Van der Pol (Switzerland).

Symposium on Microwave Optics Held at McGill University, Montreal, June 22-25, 1953

GEORGE SINCLAIR†, SENIOR MEMBER, IRE

General Remarks

A HIGHLY SUCCESSFUL SYMPOSIUM on Microwave Optics was held at the Eaton Electronics Research Laboratory, McGill University, sponsored by the Eaton Laboratory, the Electronics Research Directorate Air Force Cambridge Research Center (U.S.A.), URSI Commission VI for Canada, and URSI Commission VI for the U.S.A. The Symposium was well attended and included a number of persons from Europe and Algiers. It proved to be most stimulating to those in attendance.

The papers which were presented covered a wide range of topics, as can be seen from the titles of the sessions: Scattering Theory, Electromagnetic Diffraction, Microwave Optical Systems and Aberrations, Fourier Transforms and Information Theory, Radio Lenses. In general the majority of the papers dealt with various aspects of solving boundary-value problems, in which the boundaries involved have dimensions which are not small compared with the wavelength. Although a good deal of progress was reported at the Symposium, it became evident that there are still many difficult problems to be solved.

The Symposium clearly demonstrated the need for greater cooperation between investigators in this field, since it was evident there had been insufficient coordination of the efforts of people working on closely related projects. It is to be hoped that further symposiums will be held in the not-too-distant future.

† Sinclair Radio Laboratories, Ltd., Toronto, Canada.

Sessions on Diffraction and Electromagnetic Theory

SAMUEL SILVER†, SENIOR MEMBER, IRE

THE MICROWAVE OPTICS SYMPOSIUM as a whole dealt with a body of closely connected subjects—diffraction, scattering, and physical and geometrical optics as applied to the microwave region. The two sessions covered by this review were devoted to diffraction problems and related subjects in electromagnetic theory.

The program of these sessions was made up largely of invited papers, among which there were several by outstanding European workers in the field. We were fortunate indeed that the European scientists could attend; the personal exchange of information and ideas added to the effectiveness of the formal program.

There were two main groups of papers: one concerned with diffraction by apertures in an infinite plane conducting sheet, in particular the case of a circular aperture; the other with the development of asymptotic high-frequency solutions to Maxwell's equations and diffraction problems. The situation with regard to the problem of diffraction by apertures is that for the case of a circular aperture, whose diameter is small compared with the wavelength, there exist approximate solutions, covering both the near zone and far zone regions, which have been developed out of rigorous formulations of the problem and for which, therefore, the orders of magnitude of the errors have been established. Such solutions are clearly the asymptotic behavior of the exact solution for large wavelengths. For the case, however, when the diameter is very large compared with the wavelength, there is no corresponding solution available. By means of variational techniques, asymptotic developments have been obtained for the far zone field and for such quantities as the total cross section. A paper by Levine reported new work on the variational solution which makes use of the asymptotic form of the perturbation curents over the shadow side of the screen. These results narrow the gap between the low-frequency and infinite-frequency limits obtained previously.

The major aspect of the diffraction problem that still remains to be solved is that of the near-zone field. The

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INDEX

Transactions of the I.R.E.

Professional Group on Antennas and Propagation

Contents of Volume AP-1—1953

Volume AP-1, Number 1, July, 1953

Volume AP-1, Number 2, October, 1953

Index to Authors

Numbers refer to index numbers in contents listing. Light-face type indicates contributions, **bold-face type indicates communications.**

Index to Technical Subjects

Nontechnical Index

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